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DEMONSTRATION OF INTEGRATED SERVICES SWITCHED NETWORK FOR ADVANCED C4I AIRCRAFT

Boeing Defense and Space Group

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13. ABSTRACT (Maximum 200 words)
This effort developed a high data-rate, multimedia communications network design for an airborne platform. The network has both military and civilian applications. The results of this work may be applied to military airborne C4I platforms, such as the Airborne Warning and Control System (AWACS), the Airborne Air Command Center (AACC), and the Objective Widebody (OW). Future commercial aircraft will be supplying multimedia communications to each passenger's seat via telephones, movies, video games, and catalog ordering.

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DEMONSTRATION OF INTEGRATED SERVICES SWITCHED NETWORK FOR ADVANCED C4I AIRCRAFT

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DEMONSTRATION OF INTEGRATED SERVICES SWITCHED NETWORK FOR ADVANCED C4I AIRCRAFT

1.0 INTRODUCTION

Rapid reaction forces (RRF's) deployed to remote theaters of operation in future conflicts will increasingly have to rely on C4I assets which they bring to the theater with them. Because of their significant capability, speed of response, survivability and ability to go about anywhere, the first assets called on are usually airborne C4I platforms such as E-3 AWACS. In the future, these platforms will increasingly have to provide sophisticated battle staffs with advanced command and control decision aids and multiple off-board/on-board sensor data fusion capability, resulting in the need for a high data rate, multimedia communications network within the platform. Examples of C4I platforms currently being defined and which have extensive distributed information management needs include the Airborne Air Command Center (AACC), with an IOC of 2005, and the Objective Widebody (OW) C4I aircraft, with an IOC of around 2020. Functional requirements for future C4I aircraft will include interactive fighter control (voice), sensor data processing (including imagery) for targeting and situation assessment, real-time control of remotely piloted vehicles (RPV's) and guided weapons with sensor payloads. Data rate requirements internal to the C4I aircraft are expected to progress rapidly from 1 Mbps currently for the E-3, through approximately 5-10 Mbps for retrofits to current platforms (e.g., E-6) to 500-600 Mbps for future C4I systems.

Future commercial passenger aircrafts have similar requirements for flexible, high data rate, multimedia networks to interconnect highly distributed, external and internal computing and information resources with multiple, distributed terminal locations for passengers and crew. Commercial passenger aircraft functional requirements include telephone (voice), catalog purchases (data), movies (stream video), interactive entertainment and video conferencing (video/imagery). Our current commercial design solution for a Boeing 777 is based on 5.9 Mbps bandwidth available at each seat for video display, key pad, telephone and headset, with an aggregate requirement for the total airplane of about 500 Mbps of bandwidth.

The common denominators for both military and commercial aircraft are first, a need for wide bandwidth digital networking, and second, a need to be able to handle a wide variety of information traffic types (video/voice/data). Current hard-wired military aircraft network designs cannot satisfy the projected performance and functional requirements for future military C4I aircraft unique network (or networks) and

development of such a system would be prohibitively expensive. The most affordable and technically acceptable approach is a dual-use one based on commercial mass-produced technology.

2.0. PROGRAM OBJECTIVE

The objective of the program is to demonstrate technology readiness and to develop an architecture for implementing the airborne portion of the most demanding military distributed information environment: support of a future C4I commander and staff with real-time multimedia access to computing assets both off-board and on-board the C4I aircraft. The proposed solution is an integrated services switched network (ISSN) which we are currently evaluating for application to future commercial aircraft. This technology is dual use in that the networking concepts are fully applicable to both military C4I aircraft and to commercial passenger aircraft. The performance of commercial technology in this area significantly exceeds equivalent military technology; therefore, our emphasis will be on demonstrating the applicability and readiness of this commercial aircraft concept to fulfill future military C4I aircraft requirements.

The technical effort is composed of two tasks. In Task 1, we demonstrated a unique multimedia architecture, developed to meet the needs of the occupants of a C4I aircraft. However, the technology is fully dual use and equally applicable to commercial passenger aircraft. This system is not available currently, is light-weight and affordable, and meets the C4I aircraft commander's needs. Task 1 is described in detail in Part I.

In Task 2, we defined and developed a design for future C4I aircraft based on commercial standards and technology, and on candidate commercial aircraft hardware. Commercial technology results in a least cost approach. High performance and light-weight make the approach also applicable to other areas where C4I functions are accomplished in a constricted environment, e.g., in ground mobile command posts or on command ships. Task 2 is described in detail in Part II.

PART I

DEMONSTRATION OF CROSSPOINT SWITCH-BASED INTEGRATED SERVICES SWITCHED NETWORK

PART I. DEMONSTRATION OF CROSSPOINT SWITCH-BASED INTEGRATED SERVICES SWITCHED NETWORK

1.0. OBJECTIVE

The objective in Part I of this program is to demonstrate the crosspoint switch-based ISSN that will be capable of carrying up to four multimedia channels of mixed signals of video, audio, and data using two key technologies; time-division multiplexing and routing (switching). The crosspoint switch serves as a headend router. The time division multiplexer is used for combining up to four channels onto one serial optical output and the wavelength division multiplexer is used to achieve duplex transmission capability. The key features of this system are, multimedia switching capability without signaling or routing protocol, use of switched architecture with manual connection setup, and use of COTS hardware.

2.0. BASELINE ARCHITECTURE DESIGN

2.1. Design Approach

The architecture design is based on the previous design trade studies on a commercial airplane cabin management system (CMS). In the CMS topology, a headend unit serves as the central distribution hub for all data types while a zone management unit (ZMU) provides the secondary local hub for the various different zones of the aircraft. In this program, the headend unit and ZMU will be combined into a single unit thereby eliminating the fiber link between the two. This was done to minimize the cost of the demonstration system and no generality in concept would be lost using this approach.

The design ground-rules used are; (a) active star topology, (b) central tuner with remote selection of channels, (c) baseband signal through the distribution system, (d) no decompression at the console, and (e) compatibility with either optical or electrical transmission medium to the workstations. Based on these design ground-rules, the following approach was adopted for the demonstration system design.

a) Use of standard video transport (NTSC) format sources; audio and data to be compatible with the most commonly used industrial standard; EIA/TIA-250-C.
b) Use of time division multiplexing for multi-channel delivery over a single optical fiber reducing the cabling by a factor of four.
c) Use of a 64 x 64 crosspoint switch to more closely mimic the actual number of channels and number of workstation consoles.
d) Use of passive wavelength division multiplexing (WDM) to allow single fiber bi-directional communication between the network headend and consoles.

2.2. Demo System Architecture

The architecture of the demonstration system was derived in accordance to our general design approach. The demonstration system consists of two units, i.e., a source transmit unit (combined Headend/ZMU) and a remote receive unit interconnected by a single mode fiber. The source (transmit) unit is an IPITEK mini-chassis containing two analog-to-digital converter (A/D) boards, a digital-to-analog converter (D/A) board, a multiplexer/demultiplexer (MUX/DMUX) board, a transmitter (Tx), a receiver (Rx), and a wavelength division multiplexer (WDM), all interconnected on a central backplane. The remote (receive) unit is another IPITEK mini-chassis containing a WDM, a Tx/Rx, a MUX/DMUX board, two D/A boards, and a A/D board, all interconnected on a central backplane. The 64x64 crosspoint switch I/O will tap into the source unit's backplane and will serve as a headend router. Baseline architecture of the ISSN demo system is shown in Figure 2.2.1.

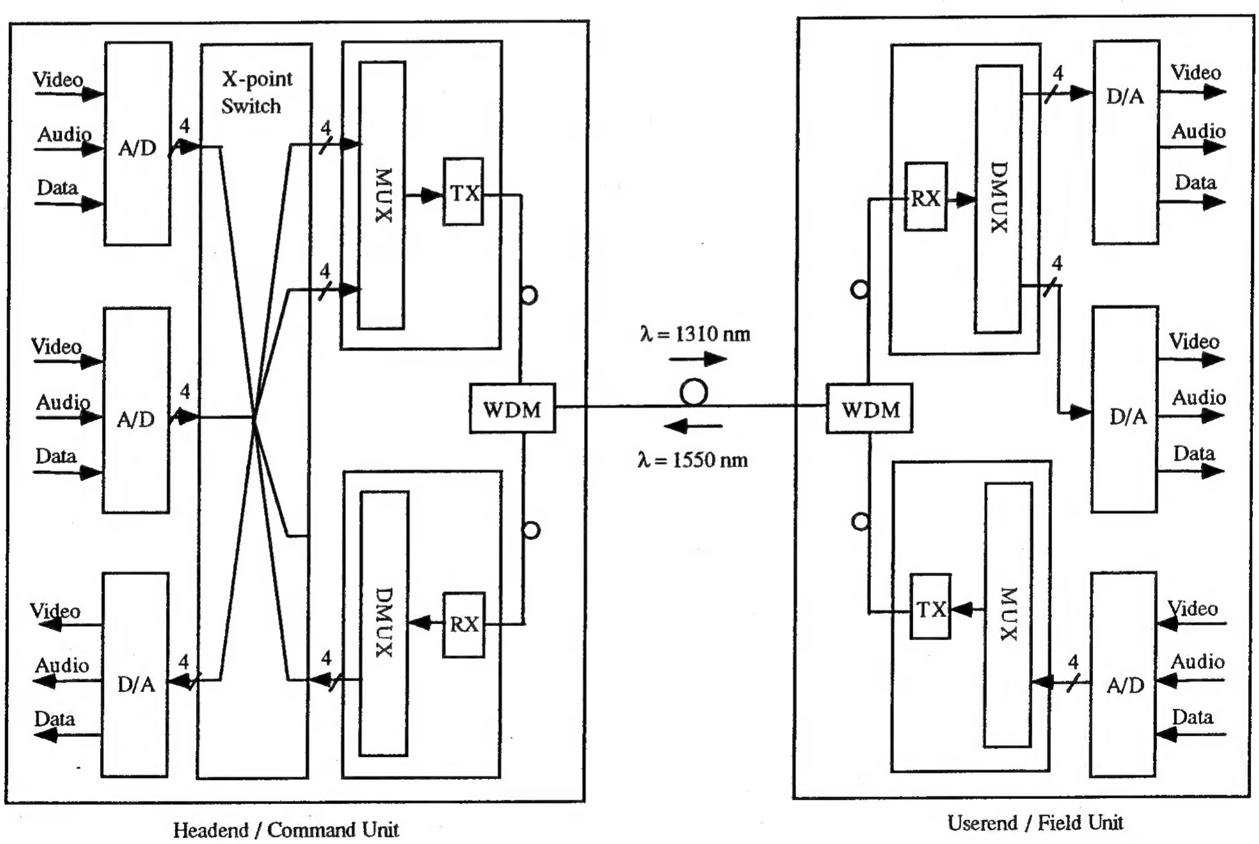


Figure 2.2.1. Baseline Architecture of the Integrated Services Switched Network

The demonstration system is capable of carrying up to four multimedia channels of mixed signals (video, audio, and data). Each A/D converter can accept one analog NTSC video source, four analog audio sources, and one RS-232 serial data source. Each converter in Figure 2.2.1 is described in more detail in Figure 2.2.2. The video, audio, and data inputs to each A/D converter are digitized into 12.5 Mbps, 8-bit video signal and a combined audio and data signal, as shown in Figure 2.2.2, and multiplexed together onto the 25 Mbps, 4-bit signal line. These four lines (as a 4-bit-wide bus) will be routed off, via the backplane, to the input of a PC-controlled crosspoint switch. Similarly, the D/A conversion process reverses the signal flow direction shown in Figure 2.2.2. The time division multiplexer combines up to four channels onto one serial optical output for an aggregate data rate of 500 Mbps. The duplex transmission capability is achieved with WDM technology using two wavelengths of 1310 and 1550 nm. The digital data signal is converted back to analog by a D/A converter and displayed on an active-matrix LCD or a standard CRT display on the receive end.

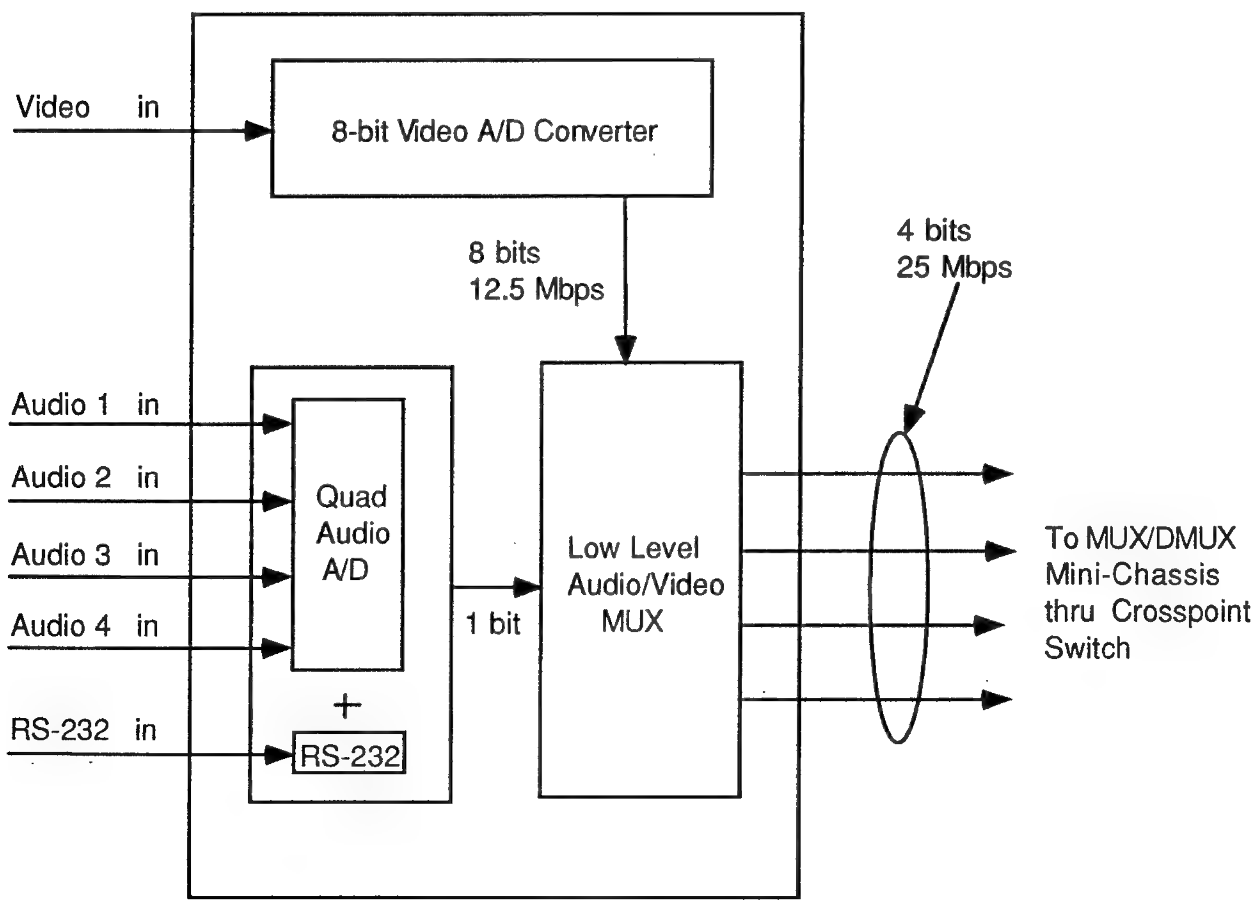
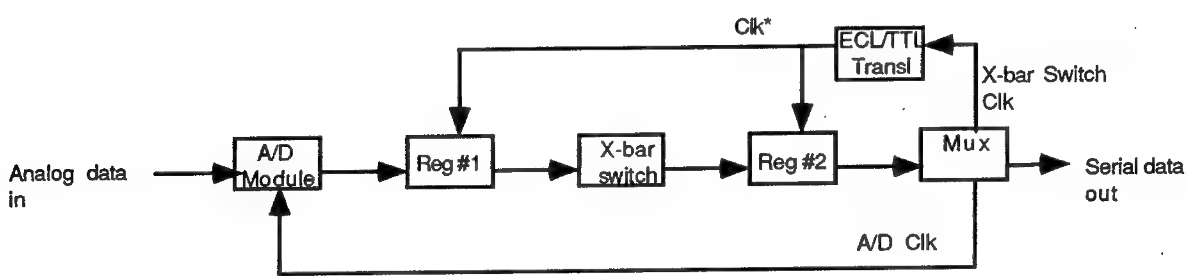


Figure 2.2.2. A/D Conversion Process for Video, Audio, and RS-232 Data

2.3. Demo System Timing Analysis

There are two ECL-level clocks required to properly synchronize the data transfer between the A/D boards and MUX board and also between the DMUX board and D/A boards. The CLKDI and CLKDI* clocks synchronize the transfer of the data from the A/D boards to the crosspoint switch, and the transfer of the data from the crosspoint switch to the MUX board. The CLKDO and CLKDO* clocks synchronize the transfer of the data from the DMUX board to the crosspoint switch, and the transfer of the data from the crosspoint switch to the D/A board. These ECL-level clocks can also be used as the clock inputs to the LSI Logic crosspoint switch chip (L64270-40). However, the L64270 crosspoint switch requires a TTL-level clock to operate its control programming functions. Thus, the clock level translation is required. As is shown in the timing control diagram (Figure 2.3.1), the ECL/TTL translator (Motorola 10H125) changes the level properly. In addition, the external pipelined registers (National Semiconductor 74ACQ374) are required at the input and output of the crosspoint switch in order to eliminate the impact of delay time associated with the introduction of the switch on the MUX and DMUX timing characteristics.



Timing Properties:
ECL/TTL Tr. T_{prop} = 1.0 - 4.0nsec
Register Tprop = 2.0 - 9.0nsec
T_{su} = 3.0nsec T_{hold} = 2.0nsec

X-bar Switch
T_{prop} = 21 - 25nsec
Mux T_{su} = 2.0nsec T_{hold} = 2.0nsec
A/D module
T_{delay} ~5-7nsec

Figure 2.3.1. Timing Characteristics and Timing Control Diagram

The data is clocked out to the A/D boards by the CLKDI, CLKDI* ECL differential clock. With the external pipelined registers around the LSI 64270 crosspoint switch chip, data is clocked into and out of the crosspoint switch logic block with the same timing as data would be normally transferred between the A/D boards and the MUX board, but delayed for one complete clock period. Data coming from the A/D board is

clocked into the input pipelined register. The previous contents of the input register, which has already passed through the L64270, will be clocked into the output pipelined register, appearing on the output of the register approximately 5 ns after the active clock edge. The MUX samples the data inputs approximately 20 ns after the active clock edge. Figure 2.3.2 and Figure 2.3.3 show the timing diagram with a clock and a clock* , respectively, out of the ECL/TTL translator.

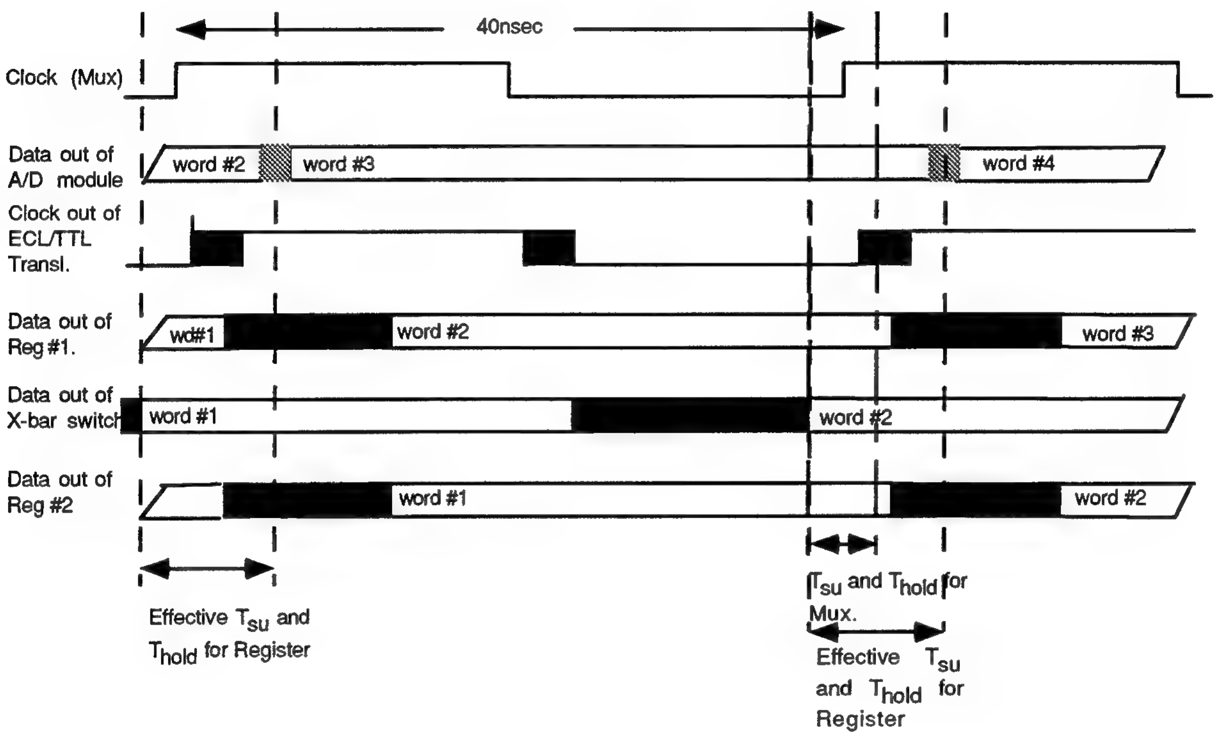


Figure 2.3.2. Timing Analysis with CLOCK from ECL/TTL Translator in the MUX-to-A/D Forward-Direction Link

Even though the actual data has been delayed one complete cycle of 40 ns from the time that it became available on the output of the A/D board, it will be fully synchronized with the timing of the MUX board. Data is clocked into the pipelined registers by the same clock which clocks the data into the output register of the A/D board. There is no delay because the delay is made transparent by the external pipelined registers. As far as the MUX is concerned, it can not see the difference between receiving data from the A/D board directly or from the output pipelined register of the crosspoint switch logic block. The same scenario applies to the data coming from the DMUX board to the D/A board.

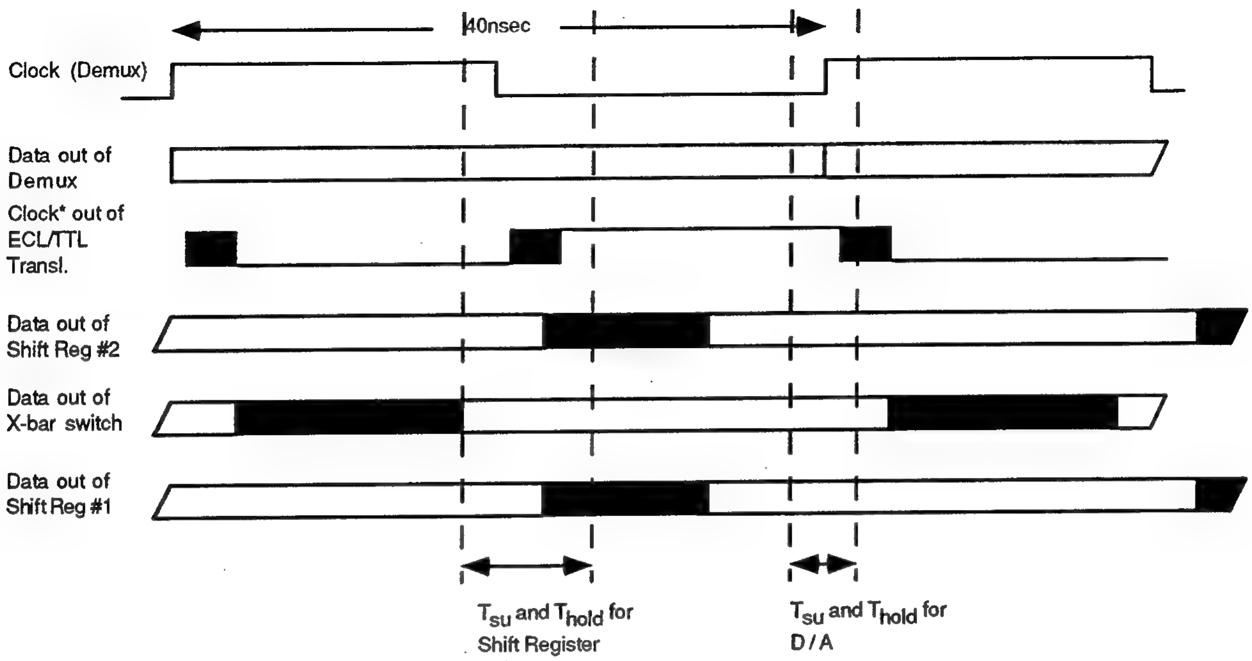


Figure 2.3.3. Timing Analysis with CLOCK* from ECL/TTL Translator in the MUX-to-A/D Forward-Direction Link

3.0. CROSSPOINT SWITCH BOARD DESIGN AND ASSEMBLY

3.1. Crosspoint Switch Selection

The 64x64 crosspoint switch serves as a head-end router and will be effectively tapped between A/D (or D/A) and MUX (or DMUX). A trade study was performed in order to select the appropriate crosspoint switch for the demonstration system. The switch performance, switch board design issues (e.g., clock level translation, design complexity), and overall cost were compared between two major products as shown in Table 3.1.1. Based on the trade study, we selected the LSI Logic crosspoint switch for the demo system. In this switch, any of the 64 outputs can be connected to any of the 64 inputs without any blocking constraints. Each of the 64 switches can be operated in a flow-through mode with a delay of 25 ns from input to output or in a pipelined mode with a delay of 15 ns from clock to output. As described in section 2.3, the switch is selected to operate in a flow-through mode with external pipelined registers and thus the propagation delay of 25 ns is made transparent by the external pipelined registers.

Parameter	Vitesse Switch	LSI Logic Switch
Substrate, Device	GaAs, FET	Si, CMOS
I/O Ports	64 x 64	64 x 64
Scalability	Cascadable	Cascadable
Data Rate	200 Mbps	40 Mbps
Switching Capability	Broadcast	Broadcast
Functional Mode	Clocked or Flow-Through	Pipelined or Flow-Through
Directionality	Unidirectional	Bi-directional
Timing Characteristics:		
• FT-mode propagation delay	2.5-5.8 ns	25 ns
• FT-mode data skew	2.5 ns	4.0 ns
• CL-mode clock skew	2.0-3.5 ns	15 ns
• CL-mode data skew	1.5 ns	-
• ECL/TTL translator delay	1.0-4.0 ns	1.0-4.0 ns
• D-FlipFlop register delay	2.0-8.5 ns	2.0-8.5 ns
• D-FlipFlop register data skew	1.0 ns	1.0 ns
CPS Data/Clock Level	ECL/ECL	TTL/TTL
MUX Data/Clock Level	TTL/ECL	TTL/ECL
ECL/TTL Translator Requirement	Required (DATA)	Required (CLOCK)
Power Dissipation	9.4 W	0.5 W
Test Board Level Complexity	High (4 levels)	Low (2 levels)
Crosspoint Switch Cost	$850	$150

Table 3.1.1. Performance Comparison of Crosspoint Switches

3.2. Crosspoint Switch Board Design

The crosspoint switch test board was designed and fabricated. The following issues were considered in switch board design:

- IPITEK mini-chassis interface to the switch board and its backplane modification for the appropriate interfacing
- Crosspoint switch socket and adapter for easy load/unload
- Clock output option to accommodate the time delay issue associated with the introduction of a crosspoint switch
- ECL/TTL clock level translation from MUX/DMUX to crosspoint switch
- PC digital I/O interface (National Instrument PC-DIO-96 I/O card) to switch board
- Various power supplies (e.g., TTL, ECL level) and ground

- Minimum 16 data signal lines to accommodate four multimedia channels (including one extra channel for future use)
- Ground line for each group of data signal lines

The part list for crosspoint switch test board fabrication is shown in Table 3.2.1.

#	Part Description	Qty	Manufacturer	Part Number
1	Crosspoint Switch	1	LSI Logic	L64270-40
2	Switch Socket	1	Emulation Technology	AB-160-QF07Z-P12-M-1*
3	Adaptor-to-Board	1	Emulation Technology	AB-160-QF07Z-P12-M-1*
4	Register (D-Flip Flop)	4	National Semiconductor	74ACQ374
5	ECL/TTL Translator	1	Motorola	MC10H125
6	14 pin DIP Header (for ribbon cable)	4	Amphenol	842-816-14-30-6-35 Protected, straight
7	50 pin DIP Header (for ribbon cable)	2	Amphenol	842-816-50-30-6-35 Protected, straight
8	100 pin DIP Connector (for ribbon cable)	1	Robinson Nugent	P50E-100P1-S1-TG Straight, male
9	100 pin DIP Connector (for ribbon cable)	1	Robinson Nugent	P50E-100S-TG Straight, female
10	Molex Connector	1	Molex	Molex8, 39-01-2080
11	Chip Resistors	4 4	-	130Ω 82 Ω
12	Chip Capacitors	1 13	-	0.1 μF 0.01 μF

* Switch Socket and its Adaptor-to-Board are considered as a set, so the same part number is assigned by manufacturer.

Table 3.2.1. Part List for Crosspoint Switch Test Board

Figure 3.2.1 shows the design of a crosspoint switch test board and interconnection between components. Details on switch integration will be described in section 3.3.

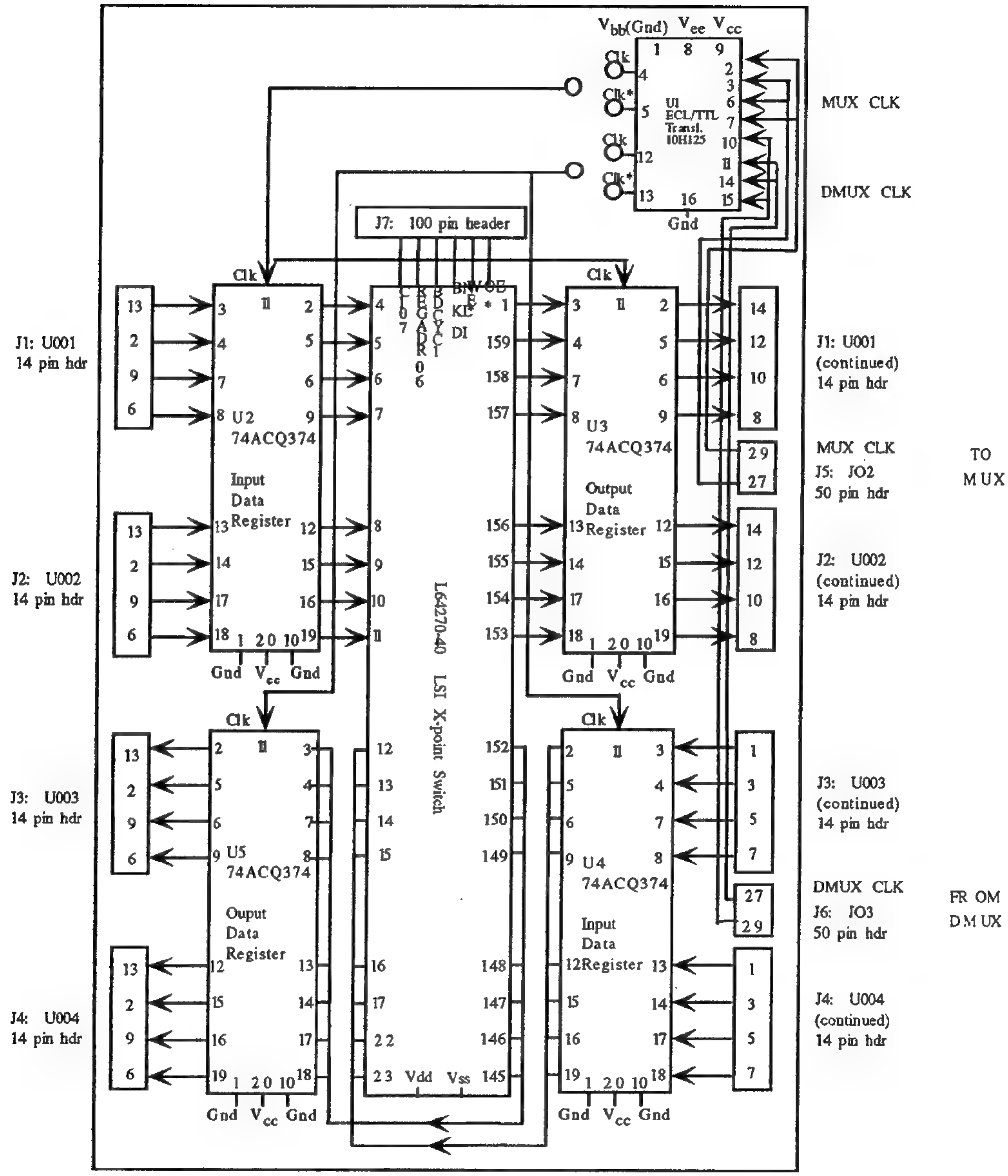


Figure 3.2.1. Crosspoint Switch Test Board Design

3.3. Crosspoint Switch Integration

The crosspoint switch on the test board is connected through the backplane to the MUX/DMUX board as shown in Figure 3.3.1.

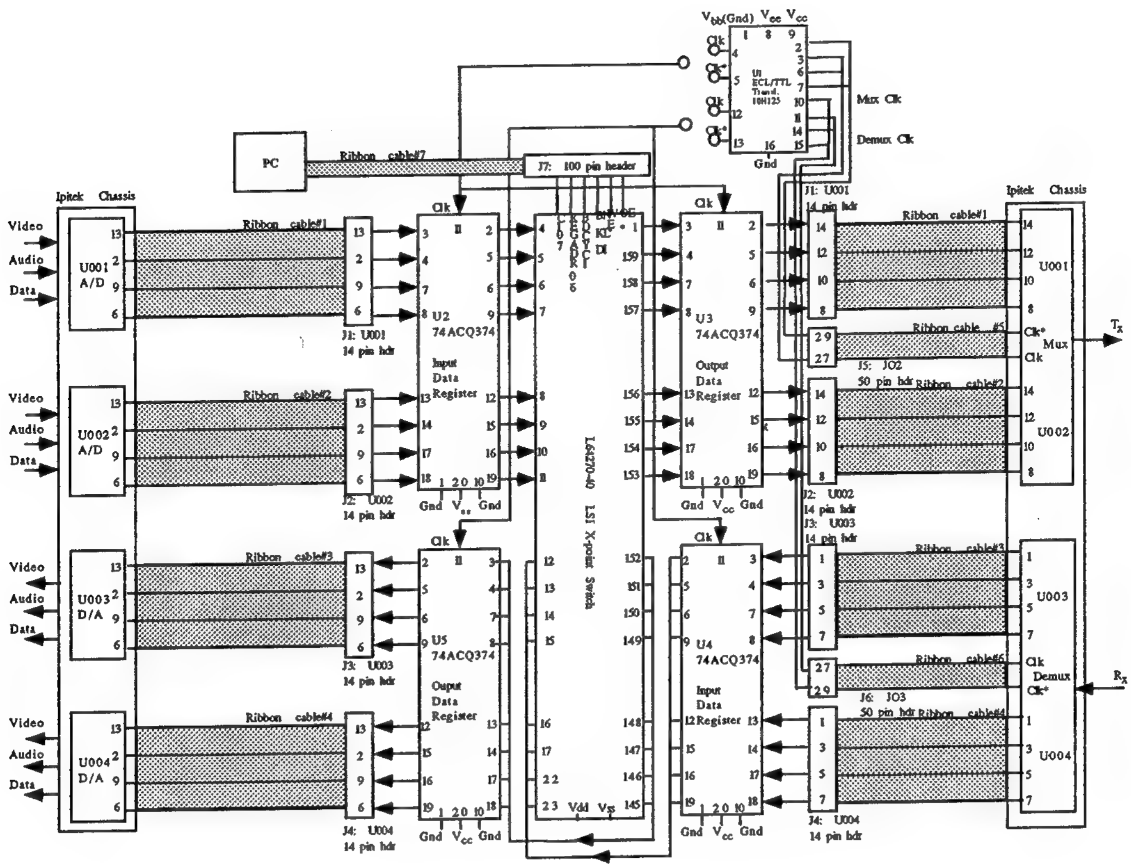


Figure 3.3.1 Crosspoint Switch Connection between A/D (D/A) and MUX (DMUX)

The 14-pin DIP sockets were installed in the U001, U002, U003, and U004 locations on the IPITEK mini-chassis backplane. These sockets are used to accept 14-pin DIP headers for interfacing the mini-chassis backplane to the external crosspoint switch interface board. The pinout from the A/D on the backplane, through the pipelined register, to the crosspoint switch is listed in Table 3.3.1 and from the crosspoint switch, through the pipelined register, to the MUX board is in Table 3.3.2. Details of the pipelined registers and ECL/TTL clock circuitry can be referred to Figure 3.3.1.

Signal Name	From A/D	To Register	Signal Name	From Register	To CPS
I-00	U001-13	U2-03	DI-00	U2-02	CPS-004
I-01	U001-02	U2-04	DI-01	U2-05	CPS-005
I-02	U001-09	U2-07	DI-02	U2-06	CPS-006
I-03	U001-06	U2-08	DI-03	U2-09	CPS-007
I-04	U002-13	U2-13	DI-04	U2-12	CPS-008
I-05	U002-02	U2-14	DI-05	U2-15	CPS-009
I-06	U002-09	U2-17	DI-06	U2-16	CPS-010
I-07	U002-06	U2-18	DI-07	U2-19	CPS-011

Table 3.3.1. A/D - Input Register - CPS Interface Connection

Signal Name	From CPS	To Register	Signal Name	From Register	To MUX
ZO-00	CPS-001	U3-03	O-00	U3-02	U001-14
ZO-01	CPS-159	U3-04	O-01	U3-05	U001-12
ZO-02	CPS-158	U3-07	O-02	U3-06	U001-10
ZO-03	CPS-157	U3-08	O-03	U3-09	U001-08
ZO-04	CPS-156	U3-13	O-04	U3-12	U002-14
ZO-05	CPS-155	U3-14	O-05	U3-15	U002-12
ZO-06	CPS-154	U3-17	O-06	U3-16	U002-10
ZO-07	CPS-153	U3-18	O-07	U3-19	U002-08

Table 3.3.2. CPS - Output Register - MUX Interface Connection

The pinout from the DMUX board, through the pipelined register, to the crosspoint switch is listed in Table 3.3.3 and from the crosspoint switch, through the pipelined register, to the D/A board is in Table 3.3.4. Details of the pipelined registers and ECL/TTL clock circuitry can be referred to Figure 3.3.1.

Signal Name	From DMUX	To Register	Signal Name	From Register	To CPS
I-08	U003-01	U4-03	DI-08	U4-02	CPS-012
I-09	U003-03	U4-04	DI-09	U4-05	CPS-013
I-10	U003-05	U4-07	DI-10	U4-06	CPS-014
I-11	U003-07	U4-08	DI-11	U4-09	CPS-015
I-12	U004-01	U4-13	DI-12	U4-12	CPS-016
I-13	U004-03	U4-14	DI-13	U4-15	CPS-017
I-14	U004-05	U4-17	DI-14	U4-16	CPS-022
I-15	U004-07	U4-18	DI-15	U4-19	CPS-023

Table 3.3.3. DMUX - Input Register - CPS Interface Connection

Signal Name	From CPS	To Register	Signal Name	From Register	To D/A
ZO-08	CPS-152	U5-03	O-08	U5-02	U003-13
ZO-09	CPS-151	U5-04	O-09	U5-05	U003-02
ZO-10	CPS-150	U5-07	O-10	U5-06	U003-09
ZO-11	CPS-149	U5-08	O-11	U5-09	U003-06
ZO-12	CPS-148	U5-13	O-12	U5-12	U004-13
ZO-13	CPS-147	U5-14	O-13	U5-15	U004-02
ZO-14	CPS-146	U5-17	O-14	U5-16	U004-09
ZO-15	CPS-145	U5-18	O-15	U5-19	U004-06

Table 3.3.4. CPS - Output Register - D/A Interface Connection

The two differential clocks CLKDI, CLKDI* and CLKDO, CLKDO* are the transmit data and receive data clocks, respectively. The CLKDI, CLKDI* clocks control the transfer of data to the MUX board and the CLKDO, CLKDO* clocks control the transfer of data from the DMUX board. These clocks and grounds are available on the IPITEK backplane of the MUX/DMUX board as shown in Table 3.3.5.

Parameter	Connector	Pin Number
CLKDI, CLKDI*	J-02	27, 29
CLK GND	J-02	30, 32
CLKDO, CLKDO*	J-03	27, 29
CLK GND	J-03	30, 32

Table 3.3.5. MUX/DMUX Clock and Clock Ground Assignment

The crosspoint switch is controlled by a PC-386 switch controller. National Instruments PC-DIO-96 digital I/O board and its associated graphical programming software, LabVIEW/Window, are installed into a PC-386 switch controller. The PC-DIO-96 is a 96-bit parallel digital I/O interface board to the crosspoint switch. The switching control program is written with the LabVIEW software and the program allows the manual setup of any connections among nodes. The interface connection between a crosspoint switch and a PC-DIO-96 digital I/O board is shown in Figure 3.3.2.

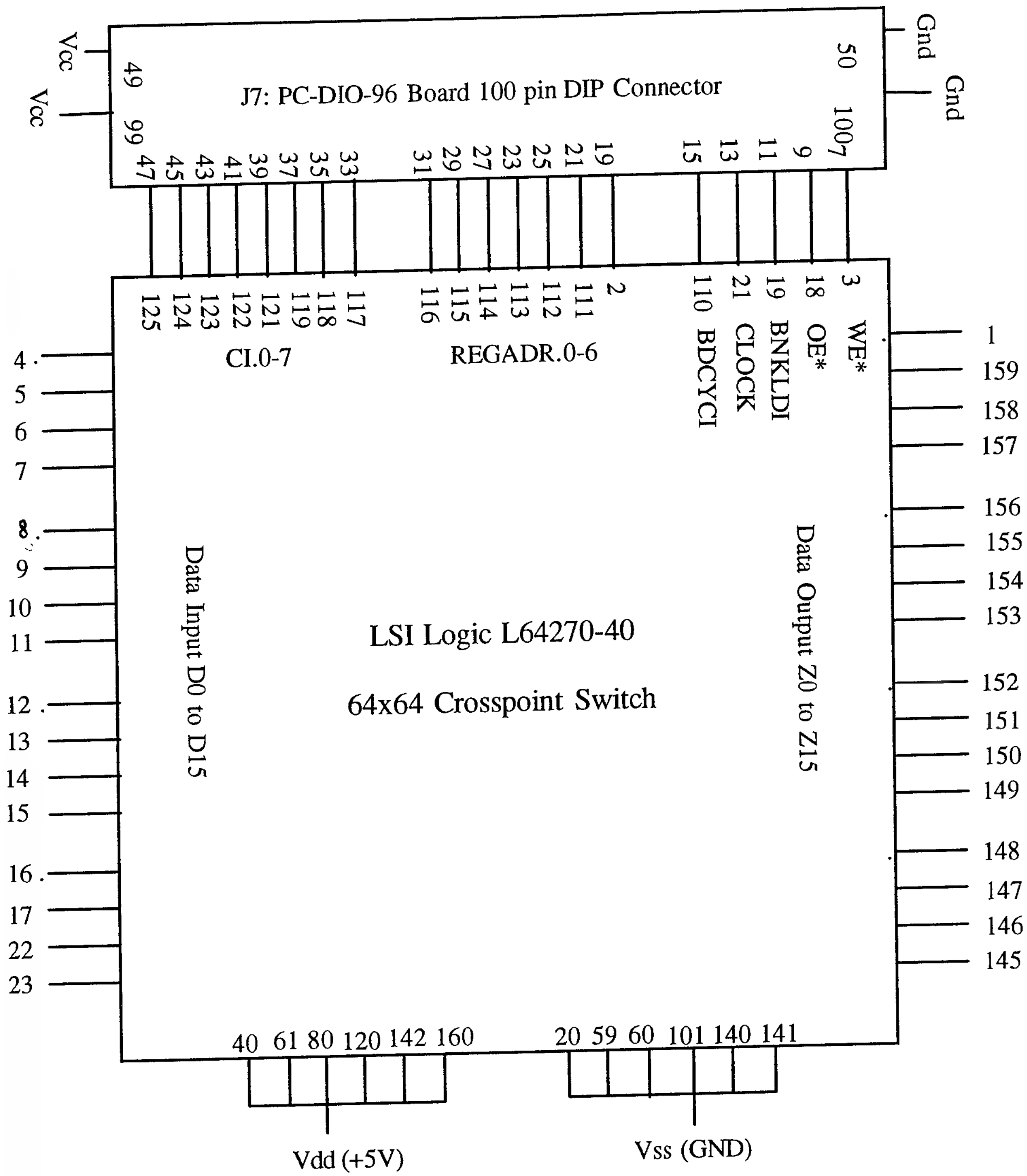


Figure 3.3.2. Crosspoint Switch Connection to Switch Controller

4.0. SYSTEM INTEGRATION

4.1. System Assembly

As described in the previous sections all major system components such as source mini-chassis, receive mini-chassis, crosspoint switch and its board, and switch controller were separately prepared. Table 4.1.1 and 4.1.2 show the major system components and auxiliary equipments list, respectively. They are assembled into the laboratory demonstration system, so called "Integrated Services Switched Network." Figure 4.1.1 shows the completed ISSN demo system diagram.

No	Part Description	Qty	Manufacturer	Part Number
1	Mini Backplane	2	IPITEK	IM-CQ-4-Mini-BP
2	Mini Chassis	2	IPITEK	IM-CQ-4-Mini-CH
3	1310 MUX/DMUX	1	IPITEK	IM-CQ-5-TxRx-1310-W
4	1550 MUX/DMUX	1	IPITEK	IM-CQ-5-TxRx-1550-W
5	A/D Board	3	IPITEK	IM-CQ-AD8-4
6	D/A Board	3	IPITEK	IM-CQ-DA8-4
7	Dual WDM	2	IPITEK	IM-CQ-4-WDM
8	AM-LCD Monitor	1	Sharp	6M-40U (5.6")
9	Digital I/O Board	1	Nat'l Instrument	PC-DIO-96/NI-DAQ
10	LabVIEW I/O SW	1	Nat'l Instrument	Basic Package

Table 4.1.1. Major System Components for Demo System

No	Part Description	Qty	Manufacturer	Part Number
1	VCR (VNS)	3	SamSung	VCR8704
2	Camcorder	2	SamSung	SCF703
3	RF Modulator	1	Pioneer	JA-RF3L
4	TV Monitor	5	Sony	N/A
5	PC-286	2	IBM PC/AT	N/A
6	PC-386/33	1	Everex	N/A
7	Audio Amplifier	2	Optimus	SA-155
8	Headphone	2	Sima	EditMike Pro

Table 4.1.2. Auxiliary Equipments for System Demonstration

Crosspoint Switch-Based
Integrated Services Switched Network Demonstration

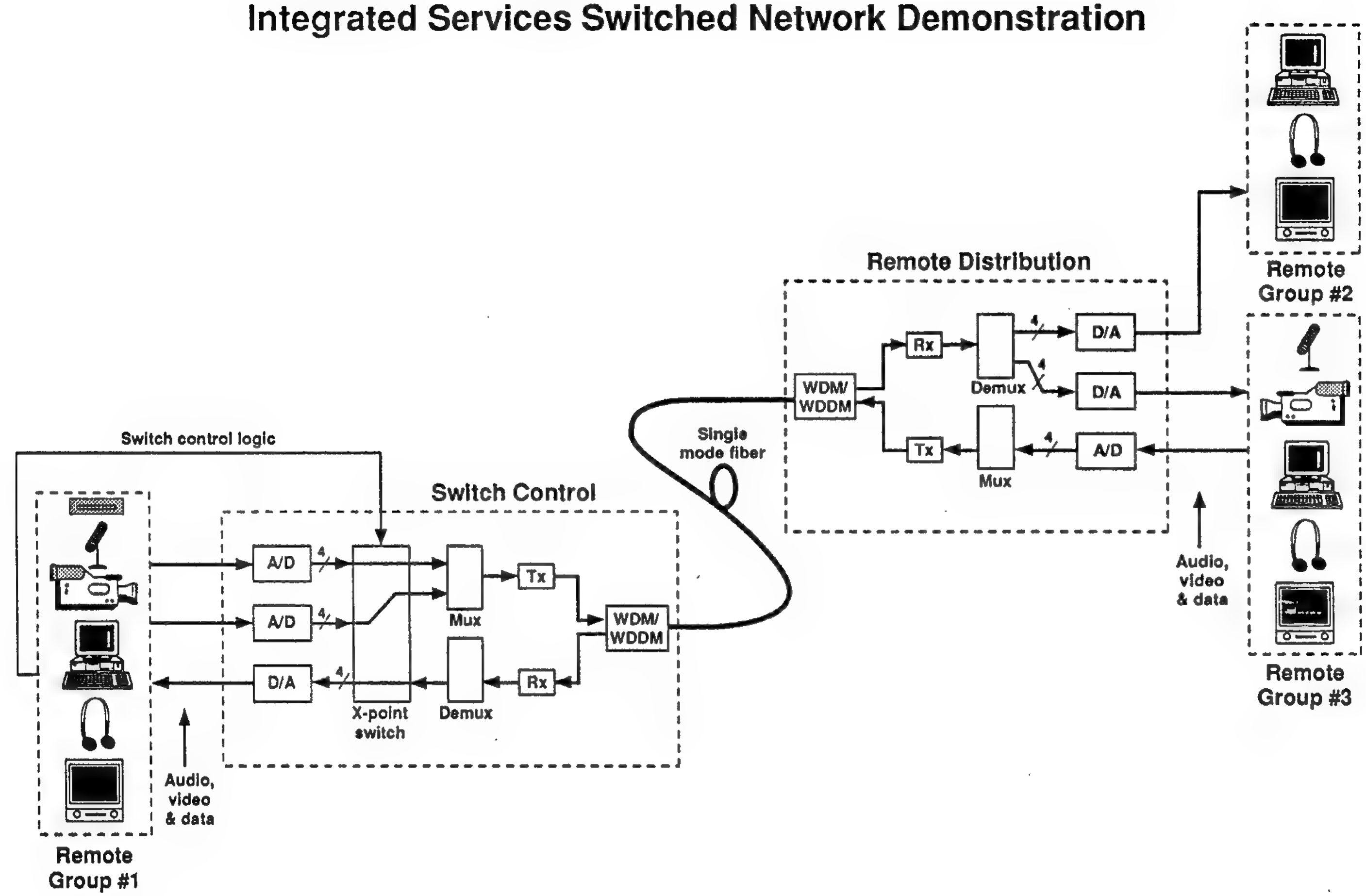


Figure 4.1.1. Completed Demonstration System Diagram

4.2. Demo System Features

Main features of the integrated demo system are as following:

- Multimedia handling capability of up to 4 video, 16 audio, and 4 RS-232 data channels
- Video resolution of industry standard 8-bit, 12.5 MHz sampling rate
- Wavelength division multiplexing technology with 1310 and 1550 nm
- Optical link budget of 28 dB (for 1310 nm link) and 22 dB (for 1550 nm link)
- Signal rate of aggregate 500-600 Mbps over single or multimode fiber
- Distance of 50 km (for single mode) and 2 km (for multimode)
- Signal quality of SNR > 67 dB (for video), SNR > 72 dB (for audio)
- Video output signal level of 1.0 Vp-p with 75 Ω termination
- Audio output signal level of 7.2 Vp-p with 50 Ω termination

5.0. SYSTEM TEST AND EVALUATION

The ISSN test and evaluation plan, developed in consultation with the customer, took advantage of the fully integrated brassboard module (mini-chassis) emphasizing the end-to-end link performance of the entire system. Individual components were tested to the manufacturer's specifications. The key tests performed by Boeing include; (a) link frame synchronization test, (b) multimedia transmission test, (c) crosspoint switch integration test, and (d) integrated multimedia switching test.

The results from qualitative testing of the crosspoint switch-based network can be used for comparison with a high level protocol oriented (i.e., self-connection setup) network such as the ATM-based network to be assessed in task 2 of the contract. The simplicity, controllability, and the quality of multimedia signals at the receive end of the crosspoint switched-based integrated services switched network is an important measure for comparison of the two approaches.

5.1. Link Frame Synchronization Test

5.1.1. Objective

To verify the functionality (e.g., frame synchronization capability) of a direct link without the crosspoint switch. The tests will ensure that the two nodes (i.e., IPITEK mini-chassis) are able to communicate by initiating and maintaining frame synchronization.

5.1.2. Approach

The two IPITEK mini-chassis will be connected to form an end-to-end link, and the basic functionality of the backplane board and the A/D, D/A, and MUX/DMUX boards will be verified. The LED indicators and test pads of the IPITEK mini-chassis

will be used to monitor the proper setup operation of the end-to-end link. In addition, the optical power will be measured to determine the link budget. All test results will be documented.

5.1.3. Test Items

a) Power supply levels on the MUX/DMUX boards
b) MUX clock generation
c) DMUX clock recovery
d) Optical link budget
e) MUX and DMUX functionality
f) A/D and D/A functionality
g) Clock recovery after link interruption
h) Clock recovery after power outage
i) Data output on the backplane board

5.1.4. Test Procedure

The system will be tested as a direct link in both uni- and bi-directional modes without any video, audio, and data input signals. This will be achieved by connecting the A/D (D/A) board directly to the MUX (DMUX) board as shown in Figure 5.1.1. A description of the test procedure is as follows:

a) Set appropriate supply voltages (for Vcc, Vtt, and Vee) to the mini-chassis. Do not apply any data input yet. Connect the two mini-chassis with a single mode fiber. Insert an optical attenuator with an enable/disable function between the two mini-chassis and set an appropriate attenuation level (approximately 5 dB). This will prevent the transmitter from oversaturating the receiver.
b) Supply voltages (but no data) to the mini-chassis. Vcc, Vtt, and Vee will be measured on test pads of the backplane board located below the bottom LED indicator for the MUX/DMUX boards.
c) Measure the clock and clock* from the MUX and DMUX, respectively (Pin 27 and 29 on J02 and J03, respectively). This verifies that the MUX and DMUX are generating and recovering the 25 MHz clock, respectively. Verify the clock frequency and logic level. This will ensure that the proper fill data is being sent between nodes to initiate and maintain synchronization of the multiplexers.
d) Measure the optical power from both the 1310 and 1550 nm transmitters at the final connector at the opposing mini-chassis. Determine the range and optical link budget of the system. The wavelength dependence of the attenuator will be taken into account.
e) Monitor the LED indicators at the front panel of the mini-chassis on the MUX/DMUX boards. This verifies proper operation of the MUX/DMUX.
f) Monitor the LED indicators at the front panel of the mini-chassis on the A/D and D/A cards. This indicates proper interfacing between the converter cards and the system.

g) The attenuator in the link will be enabled and disabled to verify the system's capability of rapidly resynchronizing after an interruption in the physical connection.
h) It will be verified that the receiving nodes recover gracefully after experiencing the network system power down or temporary breaks in the physical link.
i) Verify that the data with proper TTL levels is present at 14 pin connectors providing the access to the crosspoint switch.

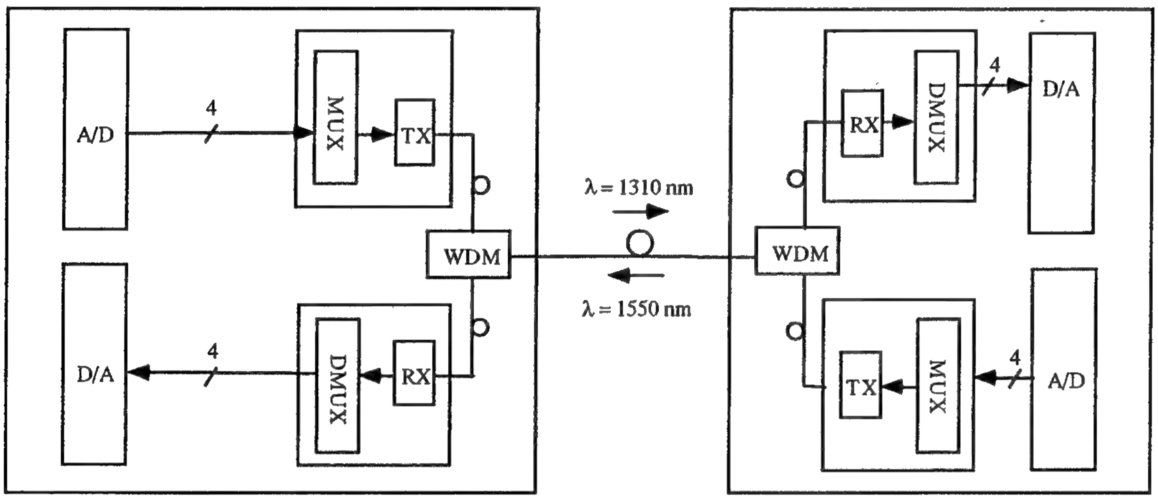


Figure 5.1.1. Network for Link Frame Synchronization Test

5.1.5. Test Results

a) Power supply levels on both source and remote MUX/DMUX boards were measured: Vee = -5.16 V, Vtt = -2.05 V, Vcc = 4.97 V at a headend board; Vee = -5.23 V, Vtt = -2.06 V, Vcc = 5.00 V at a remote board.
b) MUX clock generation was verified; the level and pulse width were 5.0 V and 40 ns, respectively for both clock and clock*.
c) DMUX clock recovery was verified; the level and pulse width were 5.0 V and 40 ns, respectively for both clock and clock*.
d) Optical link budget was measured for both directions: For a 1550 nm laser link, the sensitivity and saturation were measured to be -30 dBm and -7.0 dBm, respectively, allowing the link budget of -23 dB; for a 1310 nm laser link, the sensitivity was -28 dBm and the saturation was limited by Tx to -0.6 dBm providing the link budget of -27.4 dB. This optical link budget is compliant with the manufacturer's specification (25 ± 3 dB).
e) MUX and DMUX functionality were verified. SOURCE/PASS LEDs indicated the proper capture of baseband video signals. Tx and Rx ALARM LED monitors

indicated proper function of Tx and Rx. FRAMED LED monitors indicated DMUX properly put the data to Rx.

f) A/D and D/A functionality were verified. A/D, D/A LED fault monitors were off which indicated proper function of the A/D and D/A cards.
g) Clock recovery after link interruption was verified. Clock recovered immediately after interruption.
h) Clock recovery after power outage was verified. Clock recovered immediately after power interruption to MUX/DMUX mini-chassis.
i) Data output on the backplane board was verified. All outputs of the backplane board that would be used to interface to the switch presented the proper TTL levels of 5.0 Vp-p and pulse width of 40 ns.

In short, all components on the MUX/DMUX chassis and the end-to-end link were functional as specified.

5.2. Multimedia Transmission Test

5.2.1. Objective

To verify the bi-directional transmission of video, audio, and RS-232 data across the end-to-end link.

5.2.2. Approach

Video cameras and VCRs will provide the analog NTSC composite video and audio sources for the A/D cards. "Procomm," a commercial RS-232 communication link software package will be used for the switch controlling communications between the two PC's that will provide the RS-232 data to be transmitted across the link. A bi-directional RS-232 link will be maintained. Information will be transmitted in both directions simultaneously to verify the two-way operation of the system. All test results will be documented.

5.2.3. Test Items

a) One-way video transmission
b) Two-way video transmission
c) One-way audio transmission
d) Two-way audio transmission
e) One-way RS-232 data transmission
f) Two-way RS-232 data transmission

5.2.4. Test Procedure

The system will be tested as the end-to-end link described in Section 5.1 with multimedia signals being transmitted. The video, audio, and RS-232 data signals will be connected to each input (or output) terminal of the mini-chassis. The implementation is shown in Figure 5.2.1.

The video inputs will accept NTSC composite video signals with 1.0Vp-p (± 0.5V swing), terminated in 75W (at A/D, but not D/A). The video output that is an analog reconstruction of the NTSC composite signals, will drive a 75-W load. The audio inputs can accept 600-W balanced inputs with 7.4Vp-p (± 3.68V swing). The audio outputs can drive 50-W outputs with 7.4Vp-p (± 3.68V swing). The RS-232 data interface operates in a bi-directional mode and supports a signal rate of up to 9.6 Kbaud. Each A/D converter can support one RS-232 compatible asynchronous serial data input (for transmitting) and each D/A converter provides a serial data output (for receiving). Three video channels will be handled by the link in the demonstration. Two video channels will be transmitted in the forward direction and one in the reverse direction.

At least one single audio channel will be demonstrated along with each video signal. There will be also at least one bi-directional RS-232 link connecting two PC's.

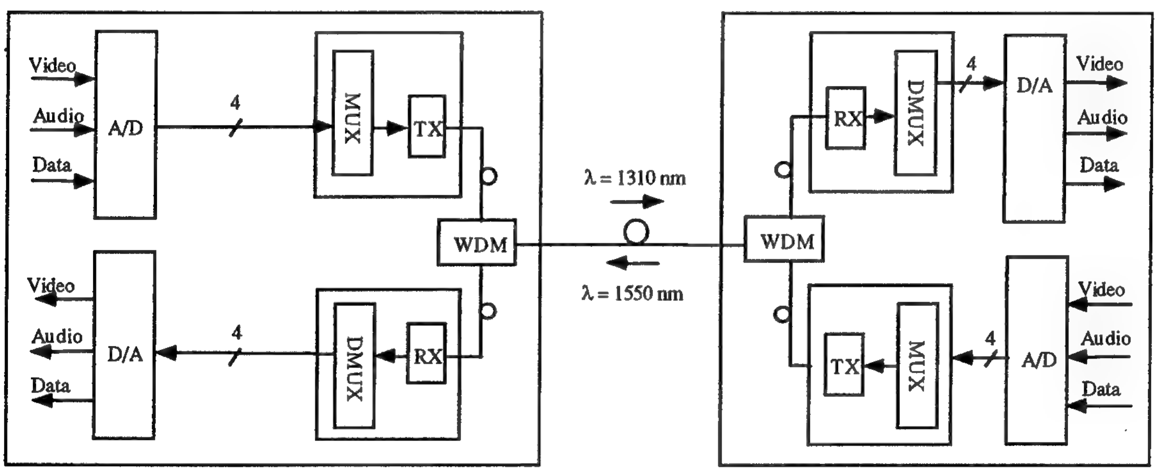


Figure 5.2.1. Network for Multimedia Signal Transmission Test

A description of the test procedure is as follows.

a) The RS-232 data, audio, and NTSC video sources on the mini-chassis at a head-end will be turned on one at a time. The quality of the video, voice, and RS-232 data at the receiving node will be recorded. Then, the sources at the user-end will be turned on to demonstrate the bi-directional operation of the system.
b) A fiber link will then be disconnected and reconnected using an enable/disable function of the attenuator to verify the system's capability of rapidly resynchronizing after an interruption in the physical connection.

c) It will be verified that the receiving node's data, audio, and video interfaces recover gracefully after experiencing the network system power down or temporary breaks in the physical link.
d) The impact on quality of video, audio, and RS-232 data will be recorded.
e) It will be verified that the quality of video, audio, and data is maintained over the link budget as determined in Section 5.1.

5.2.5. Test Results

a) One-way video transmission was verified. No negative impact on video quality was observed through the MUX/DMUX mini-chassis.
b) Two-way video transmission was verified.
c) One-way audio transmission was verified.
d) Two-way audio transmission was verified. A feedback problem was observed due to the physical proximity.
e) One-way RS-232 data transmission was verified.
f) Two-way RS-232 data transmission was verified.

In short, the end-to-end link was functioning correctly as specified. Consumer-grade TV quality of video and data were maintained during transmission across the end-to-end link in both directions. There was a feedback problem in the two-way audio mode due to the physical proximity.

5.3. Crosspoint Switch Control Test

5.3.1. Objective

To verify the proper operation of the crosspoint switch and the layout design of the switch test board. To verify the functionality of the LabVIEW/Window program written for the crosspoint switch control. This test will ensure the proper control of National Instruments PC-DIO-96 digital I/O board that interfaces with the crosspoint switch.

5.3.2. Approach

National Instruments PC-DIO-96 digital I/O board and associated software (LabVIEW/Window) will be installed into a PC-386 switch controller. The PC-DIO-96 is a 96-bit parallel digital I/O interface board (for IBM PC's) which will be connected to the crosspoint switch. The I/O board uses 24-bit programmable peripheral interfaces (PPI's) and each PPI can be divided into three 8-bit ports. All the necessary control signals of the crosspoint switch are assigned to the same PPI. LabVIEW/Window is a graphical programming software. The switching control program, that allows the manual setup of any connections among nodes, will be written using the LabVIEW software.

The switch controller outputs will be monitored with an oscilloscope after entering data into each input with a pattern generator. Whether the connections are correct and the

data is not corrupted will be verified. The situation that generates potential noises and crosstalks will be simulated using a pattern generator.

The interconnection between a crosspoint switch and a switch controller I/O board is shown in Figure 5.3.1. In this test the functionality and configurability of a crosspoint switch will be verified using the LabVIEW program. All the potential connections of the system will be entered to verify that the I/O board is providing the correct data at the outputs for controlling the crosspoint switch. The potential connections will include the singlecast and multicast/broadcast setups. All test results will be documented.

5.3.3. Test Items

a) Switch configuration setup
b) Singlecast connections
c) Multicast/broadcast connections

5.3.4. Test Procedure

Verify correct outputs for configuring the switch, for example, 4-bit wide bus, flow-through, uni-directional mode operation. Then, determine the translation between a desired connection and the I/O outputs. Enter all potential connection configuration requests on the switch controller PC and verify that the actual outputs of the I/O card correspond to the predicted outputs. This will be accomplished using a pattern generator and an oscilloscope.

The interconnection of the crosspoint switch between A/D (D/A) and MUX (DMUX) is shown in Figure 3.3.1. Verify that the crosspoint switch is properly switching 4-bit wide words in the uni-directional, flow-through mode. Determine the translation between the desired connection request and inputs/outputs of the crosspoint switch board. Then, enter all potential connection requests on the PC and verify that the data outputs of the crosspoint switch board correspond to the data inputs.

5.3.5. Test Results

The output of the PC-DIO-96 was verified for the various mode configurations required to operate the crosspoint switch. Figure 5.3.1 shows the pin translations between the PC-DIO-96 board and the crosspoint switch adapter pins.

First, the following parameters were set up in order to program the crosspoint switch to the proper operation mode:

BDCYC1: Low for unidirectional switch
BNKLDI: High for flow-through mode
PMODE: High for bus output to be pipilined
C1.6: Low for automatically enabling output drivers

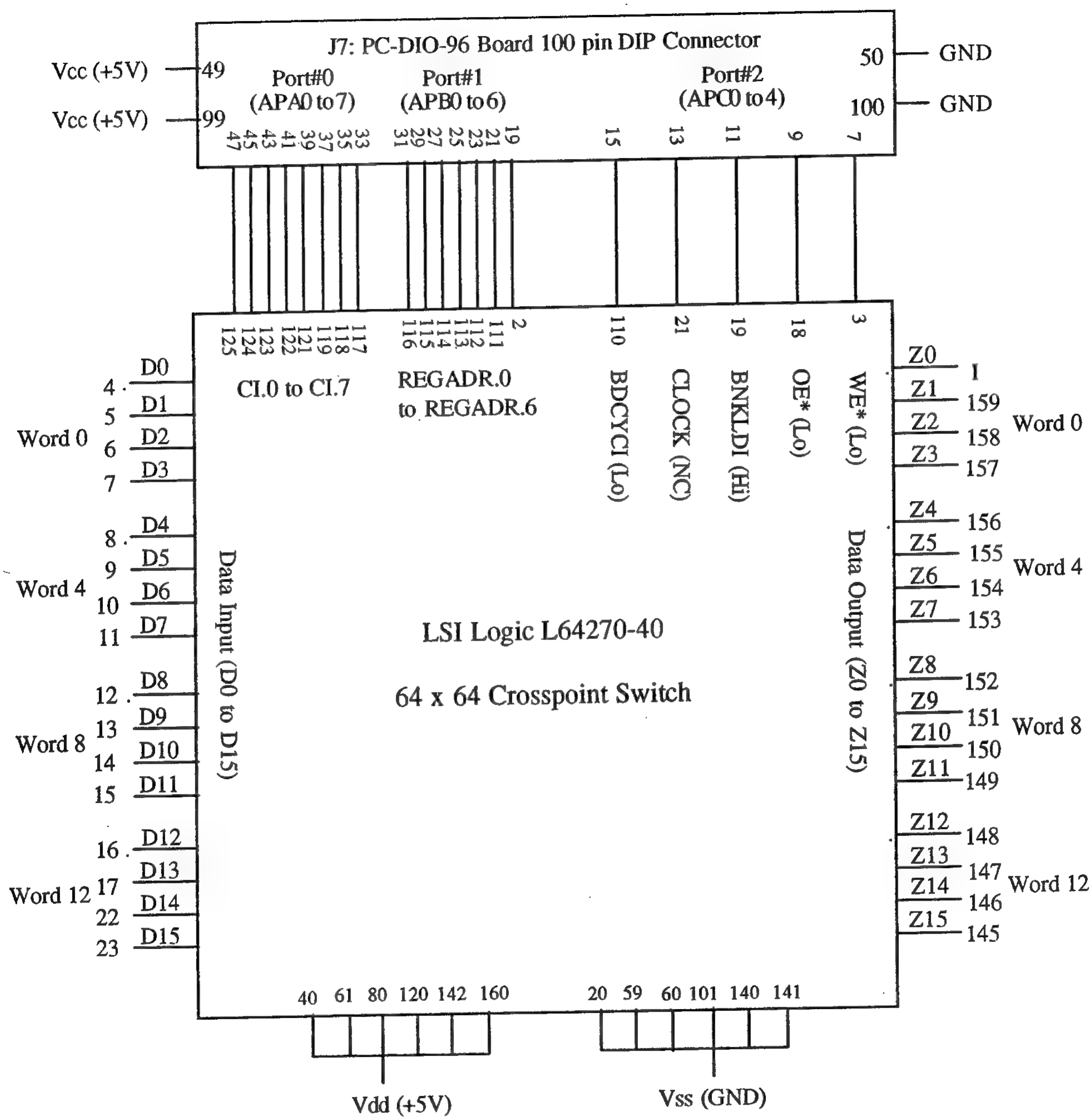


Figure 5.3.1. PC-DIO-96 Board to CPS Adaptor Pin Assignment

Second, the crosspoint switch controller (PC-DIO-96) digital I/O ports were assigned to the crosspoint switch's relevant pins:
Port # 0 (APA 0 to 7): Control input bus, CI.0 - CI.7
Port # 1 (APB 0 to 6): Address on control register, REGADR.0 - REGADR.6
Port # 2 (APC 0 to 4): All other switch parameters, BDCYC1, CLK, BNKLDI, OE*, WE*
The configuration setup (Table 5.3.1) was verified on the crosspoint switch board.

Port 0	Parameter	CI.7	CI.6	CI.5	CI.4	CI.3	CI.2	CI.1	CI.0
	Board pin #	33	35	37	39	41	43	45	47
	Expected level	0	0	0	0	0	0	1	1
	Measured level	0	0	0	0	0	0	1	1

Port 1	Parameter	REGADR .7	REG .6	REG .5	REG .4	REG .3	REG .2	REG .1	REG .0
	Board pin #	19	21	23	25	27	29	31	33
	Expected level	1	0	0	0	0	0	0	0
	Measured level	1	0	0	0	0	0	0	0

Port 2	Parameter	N/A	N/A	N/A	WE*	OE*	BNKLDI	CLK	BDCYC1
	Board pin #	1	3	5	7	9	11	13	15
	Expected level	0	0	0	1	0	1	0	0
	Measured level	0	0	0	1	0	1	0	0

Table 5.3.1. Configuration Setup of Crosspoint Switch Board

Then, the configuration was verified on the crosspoint switch board.
First, the switch inputs DI.0 - DI.3 (input word 0) to outputs Z.0 - Z.3 (output word 0) as shown in Table 5.3.2.

Port 0	Parameter	CI.7	CI.6	CI.5	CI.4	CI.3	CI.2	CI.1	CI.0
	Board pin #	33	35	37	39	41	43	45	47
	Expected level	0	0	0	0	0	0	0	0
	Measured level	0	0	0	0	0	0	0	0

Port 1	Parameter	REGADR .7	REG .6	REG .5	REG .4	REG .3	REG .2	REG .1	REG .0
	Board pin #	19	21	23	25	27	29	31	33
	Expected level	0	0	0	0	0	0	0	0
	Measured level	0	0	0	0/1	0	0	0	0

Port 2	Parameter	N/A	N/A	N/A	WE*	OE*	BNKLDI	CLK	BDCYC1
	Board pin #	1	3	5	7	9	11	13	15
	Expected level	0	0	0	1	0	1	0	0
	Measured level	0	0	0	1	0	1	0	0

Table 5.3.2. Crosspoint Switch Board Input/Output (DI.0-DI.3/Z.0-Z.3) Setup

Second,the switch inputs DI.4 - DI.7 (input word 4) to outputs Z.4 - Z.7 (output word 4) as shown in Table 5.3.3.

Port 0	Parameter	CI.7	CI.6	CI.5	CI.4	CI.3	CI.2	CI.1	CI.0
	Board pin #	33	35	37	39	41	43	45	47
	Expected level	0	0	0	0	0	1	0	0
	Measured level	0	0	0	0	0	1	0	0

Port 1	Parameter	REGADR .7	REG .6	REG .5	REG .4	REG .3	REG .2	REG .1	REG .0
	Board pin #	19	21	23	25	27	29	31	33
	Expected level	0	0	0	1	1	0	0	0
	Measured level	0	0	0	1	1	0	0	0

Port 2	Parameter	N/A	N/A	N/A	WE*	OE*	BNKLDI	CLK	BDCYC1
	Board pin #	1	3	5	7	9	11	13	15
	Expected level	0	0	0	1	0	1	0	0
	Measured level	0	0	0	1	0	1	0	0

Table 5.3.3. Crosspoint Switch Board Input/Output (DI.4-DI.7/Z.4-Z.7) Setup

In short, the PC-DIO-96 Digital I/O's communicate correctly with the crosspoint switch I/O's. This implies that the crosspoint switch board layout is also correct. Test board functionality is verified indirectly through the switched multimedia tests in section 5.4.

5.4. Integrated Multimedia Switching Test

5.4.1. Objective

To verify the end-to-end functionality of the fully integrated switched multimedia network with the crosspoint switch.

5.4.2. Approach

The system test will utilize the fully integrated switched network emphasizing the end-to-end link functionality and performance of the entire system. The crosspoint switch will be connected, through the mini-chassis backplane board, between A/D (D/A) and MUX (DMUX). By controlling the crosspoint switch through a LabVIEW Window program, the signal routing capability (singlecast and multicast/broadcast) will be tested. The system functionality of multimedia signal transmission will be tested by simultaneously transmitting NTSC video, audio, and data on the same channel. The results from qualitative testing of the crosspoint switch network will be used for comparison with a high level protocol oriented (i.e., self-connection setup) network such as the ATM network to be assessed in Task 2. All test results will be documented.

5.4.3. Test Items

a) Simplex multimedia (video, audio and data) signal switching (singlecasting)
b) Simplex multimedia signal switching (multicasting/broadcasting)
c) Bi-directional multimedia information transmission

5.4.4. Test Procedure

The implementation diagram for this fully integrated switched multimedia signal transmission test is shown in Figure 5.4.1. All tests in Section 5.2 will be repeated with a crosspoint switch connected and the test procedure will be the same as before (refer to the test procedure in Section 5.2.4). All of the potential connection scenarios will be entered on the switch controller and the multimedia information quality will be assessed and recorded.

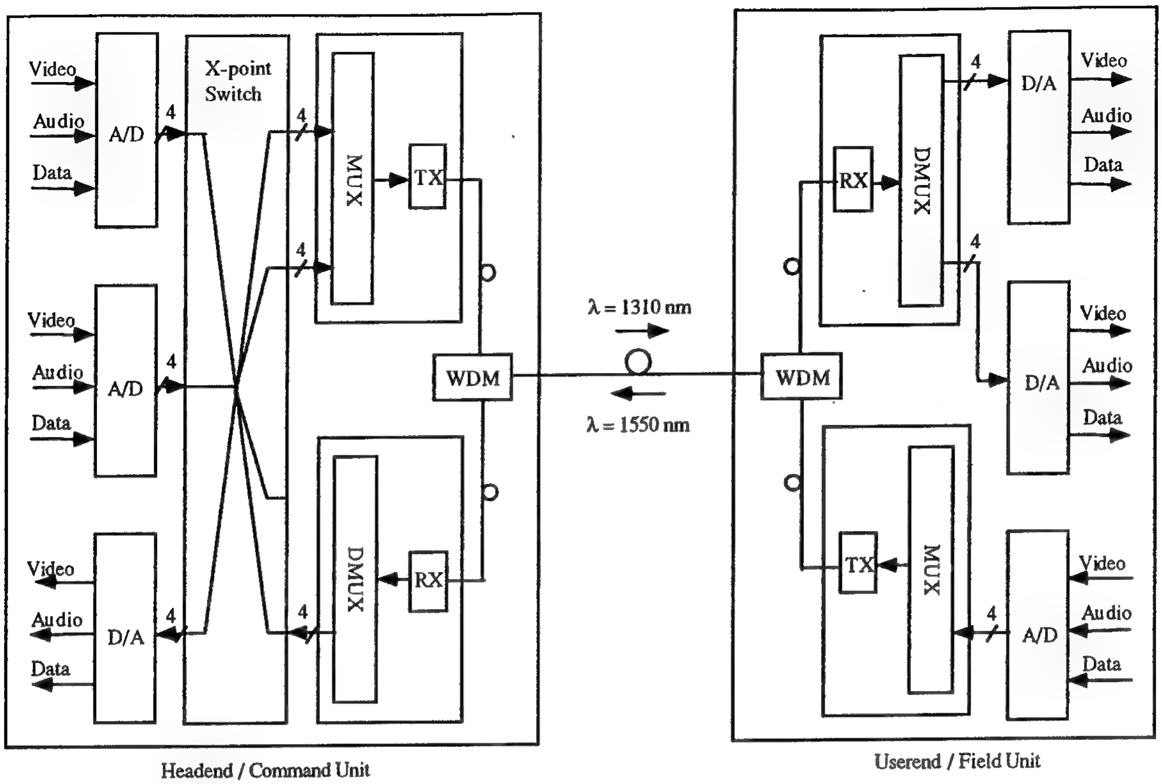


Figure 5.4.1. Network for Switched Multimedia Signal Transmission Test

5.4.5. Test Results

The fully integrated switched multimedia network functionality was tested in a specified routing configuration (singlecast and multicast/broadcast). The integrated services switched network (ISSN) was mostly able to successfully distribute high quality multimedia information between a head-end and a user-end. For convenience, we will call a head-end unit as control center (CC) and user-end unit as remote terminal (RT).

5.4.5.1. Simplex and Duplex Singlecasting Test

A. CC video camera to RT-1

Video: Video quality is good and without speckle in both directions.

Audio: Audio quality is good in both directions except RT-1 has slight static. Note that audio is very sensitive to background noise and also to the change of crosspoint switch power supply. It was found that Vcc = +4.25 V, -5.10 V was the optimum value, and a very narrow window existed for satisfactory video and audio quality.

Data: Using Procomm, a commercial RS-232 communication link software package, e-mail messages were successfully transmitted in both directions. File transmission was also tested in both directions using an XMODEM protocol. During repeated tests, zero to three errors were detected in 100KB files.

B. CC VCR to RT-1

Video: Video quality looks very good in both directions. No speckle.

Audio: Audio quality is good in both directions. No static.

Data: No capability in this mode.

C. CC video camera to RT-2

Video: Video quality is good except for a small amount of speckle. This could be eliminated by adjusting (decreasing) a crosspoint switch power supply, but this in turn will degrade audio quality. Thus, a narrow range exists for the optimum power supply value for satisfactory media transmission.

Audio: Audio quality is good in both directions except for a slight background static.

Data: E-mail messages were successfully transmitted from CC to RT-2. No errors were detected for the 3 to 4 row message of same characters. File transmission failed as expected due to the simplex connection which does not allow handshaking.

D. CC VCR to RT-2

Video: Video quality looks good in both directions. Slight speckle.

Audio: Audio quality is good in both directions. No static.

Data: Design does not allow this capability.

E. CC video camera to CC

Video: Video has a severe noise and frame jumping problem.

Audio: Audio has continuous static problem and does not play back at all.

Data: Design does not allow this capability.

F. CC VCR to CC

Video: Video has a severe noise and frame jumping problem.

Audio: Audio is playing back with a severe static problem.

Data: Design does not allow this capability.

G. RT video camera, VCR to RT-1

Video: Video has a severe noise and frame jumping problem. RT-2 also has degraded video in this mode even though it is receiving CC VCR.

Audio: Audio is playing back with a severe static problem. RT-2 has degraded audio in this mode even though it is receiving CC VCR.

Data: Errors are continuously generated.

H. RT video camera, VCR to RT-2
Video: Video has a severe noise and frame jumping problem. RT-1 is not negatively impacted.
Audio: Audio is playing back with a severe static problem.
Data: Errors are generated.

5.4.5.2. Simplex and Duplex Multicasting/Broadcasting Test

A. CC video camera to RT-1 and RT-2
Video: Video quality is good and no speckle in RT-1, but slight speckle in RT-2.
Audio: Audio quality is good in both RT-1 and RT-2. No static.
Data: E-mail messages were successfully transmitted from CC to RT-1 and RT-2. No errors were detected for the 3 to 4 row message of same characters. File transmission to RT-1 was also tested in both directions using an XMODEM protocol, but not to RT-2 (no handshaking capability). During repeated tests, one to three errors were detected in 100KB files.

B. CC VCR to RT-1 and RT-2
Video: Video quality is good and no speckle in both RT-1 and RT-2.
Audio: Audio quality is good with very little static.
Data: Same as A.

C. CC video camera to RT-1, RT-2, and CC
Video: Video quality is good and no speckle in both RT-1 and RT-2.
Audio: Audio quality is good with very little static.
Data: Same as A.

D. CC VCR to RT-1, RT-2, and CC
Video: Video has frame jumping problem in both RT-1 and RT-2.
Audio: Audio quality is good with very little static.
Data: Same as A.

E. RT-1 VCR to RT-1, RT-2, and CC
Video: Video quality is good and no speckle in both RT-1 and RT-2.
Audio: Audio quality is good with very little static.
Data: Same as A.

6.0. CONCLUSION

Boeing demonstrated successfully a crosspoint switch-based system in Task 1 of the Integrated Services Switched Network (ISSN) program. The key features of this phase of the ISSN demonstration are the use of COTS hardware, the absence of a communications protocol, the use of switched (as opposed to shared) architecture, and a centralized connection setup. The absence of a signaling and routing protocol simplified the architecture significantly. Circuit switching eliminated resource sharing and potentially contention-related data loss and latency as well. The scheme had less need for compression technology due to the availability of relatively high bandwidth and thus would not require MPEG encoder/decoders. This in turn minimized the potential for information loss and associated delays caused by lossy compression algorithms. This is an important issue for many applications such as high resolution imagery/sensor data that is used for target identification. In addition, although it is limited by the crosspoint switch capacity, the architecture can be scaleable for future growth in either a centralized or a distributed configuration. Figure 6.1.1 and Figure 6.1.2 show top-level logical connection schemes for centralized and distributed crosspoint switched-based integrated services switched networks, respectively.

However, although the crosspoint architecture is simple, it is not easy to integrate (or interoperate) with existing commercial broadband networks. It requires a parallel low-rate control network for the setup of connections between source and destination. Additionally, the architecture does not have the flexibility to share network resources dynamically using statistical multiplexing. Therefore, a design study on ATM-based ISSN for future C4I aircraft is performed in Task 2 of this program. Part II of this report will describe in detail the design study of ATM-based ISSN.

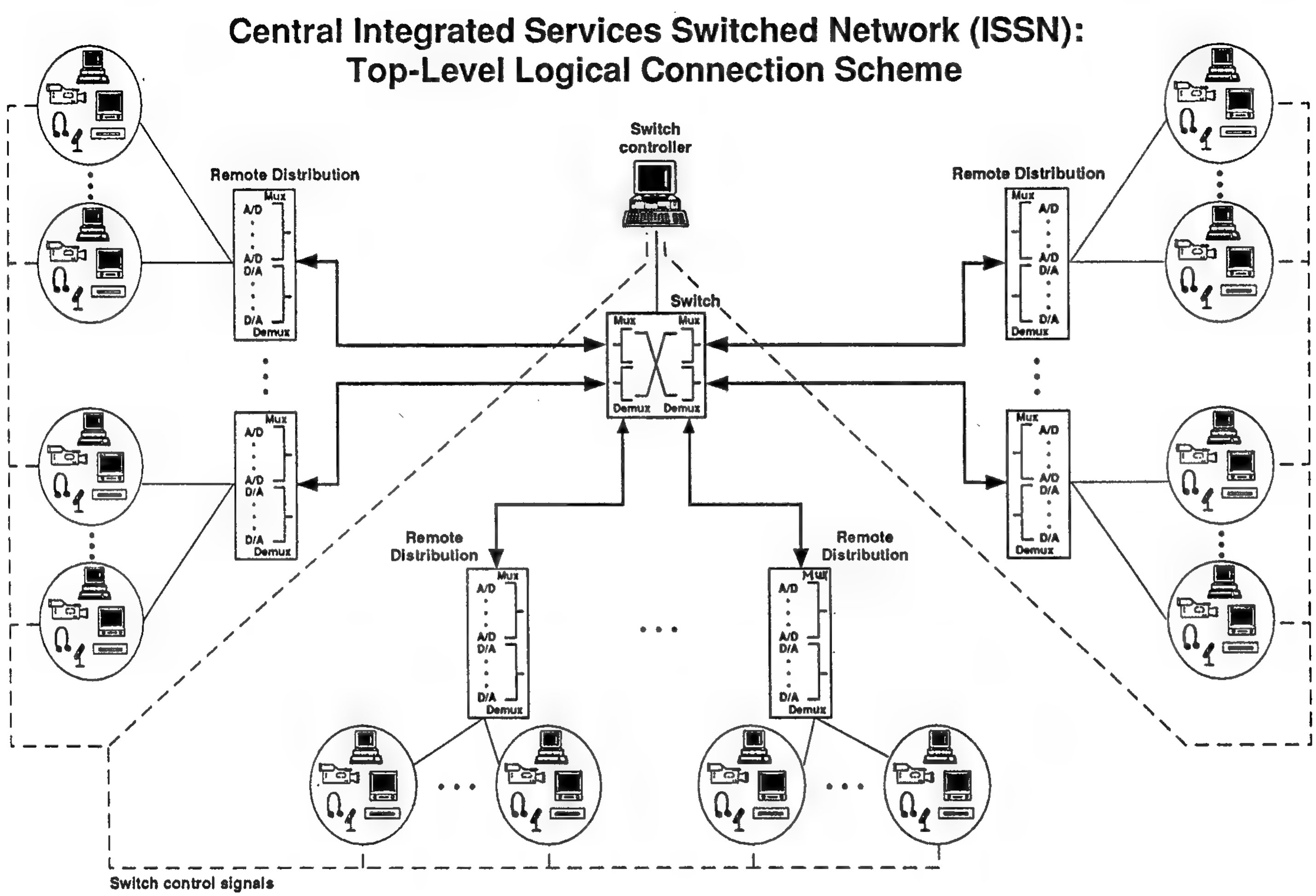


Figure 6.1.1. Top-Level Logical Connection Scheme for Centralized Crosspoint Switch-based Integrated Services Switched Network

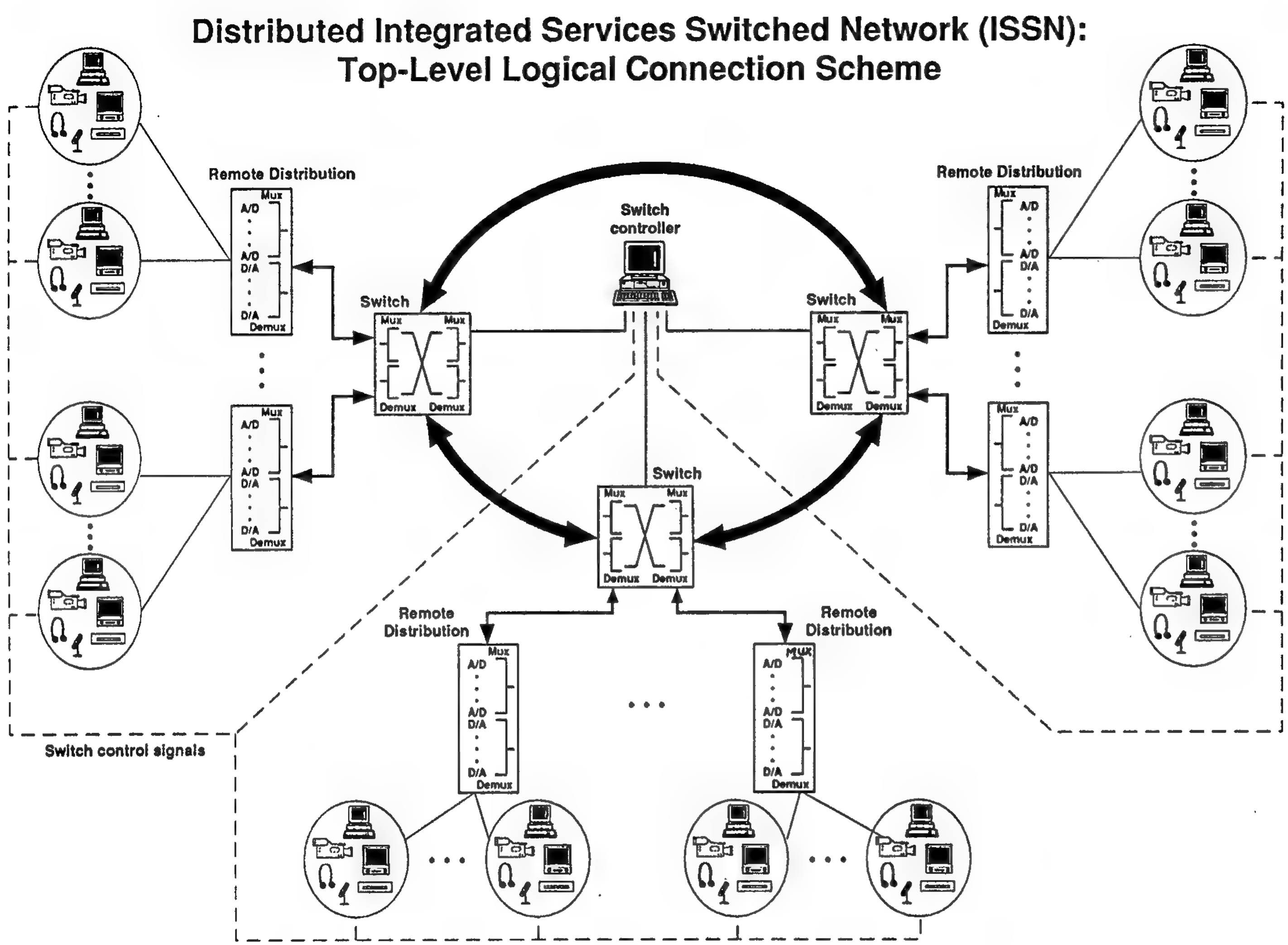


Figure 6.1.2. Top-Level Logical Connection Scheme for Distributed Crosspoint Switch-based Integrated Services Switched Network

PART II

DESIGN STUDY ON ATM-BASED INTEGRATED SERVICES SWITCHED NETWORK FOR FUTURE C4I AIRCRAFT

PART II. DESIGN STUDY ON ATM-BASED INTEGRATED SERVICES SWITCHED NETWORK FOR FUTURE C4I AIRCRAFT

1.0. OBJECTIVE

The architecture for future integrated services switched network (ISSN) will take advantage of Asynchronous Transfer Mode (ATM) technology to provide the network capacity for a wide variety of applications ranging from highly-interactive to minimally-interactive systems. The objective in part II of this program is to perform a feasibility study for implementing the ATM-based ISSN network for the next generation C4I aircrafts. Advanced C4I aircraft on-board network requirements will be collected and compiled to form the basis for the ISSN requirements. The design study will be performed through a network architecture and technology trade. Relevant trade elements and parameters will be documented to form the basis for the template of a network trade. The conclusion will verify the compatibility of the downselected network design with the collected ISSN requirements and compare it with the crosspoint switch-based ISSN demo system described in Part I.

The following program requirements are preliminary and are subject to change as mission needs are revised. The trade is similarly subject to revision as networking technology and C4I mission requirements change.

2.0. C4I AIRCRAFT ISSN REQUIREMENTS

2.1. High level requirements

a) Integrated system: Provide an integrated digital information network that supports the C4I systems.
b) Space-based platform: Provide an assured access to the mission-essential military and commercial space-based systems; satellite communications, global positioning systems.
c) Affordability: Provide an architecture that supports an open system concept, insertion and use of commercial and openly available military technology, and the reuse of software.
d) Open system adaptability: Provide an open architecture that allows modules built by different vendors to be compatible with each other.
e) Data rate: Provide an architecture that supports the projected data rate for various electro-optic, radar, electronic warfare, communications, navigation, and identification applications.

f) Commercial technology: Provide C4I capabilities that leverage commercial technology; provide the architecture that relies heavily on commercial software and hardware technology to control costs.
g) Interoperability: Provide a C4I system that interoperates in combined operations.
h) Multi-level security: Provide an ability to access and exchange information at various levels of security classification using a single network.
i) Reliability and supportability: Provide an architecture that addresses reliability, maintainability, and supportability such as fault tolerance and imbedded diagnostics capability.
j) Technology independence and growth: Provide an architecture that minimizes the reliance on specific technology implementations and supports the upgradability without requiring major redesign.
k) Scalability: Provide an architecture that meets the current and future need to adapt to a wide range of projected mission requirements and systems.

2.2. Network requirements

Table 2.2.1 lists the relevant network parameters, sources of specific requirements, requirements, and the ISSN capabilities necessary to support these requirements. The ISSN capabilities are made sufficiently flexible to be a solution for a maximum number of C4I platforms.

Network Parameters	Platform	ISSN Capability
1. Network Design		
• Network size (# of nodes)	E-3 JACC	90 Terminals
• Network types	VC-X JACE	ATM switching
• Connection capability	VC-X	Broadcasting
• Distribution signal format	VC-X	Digital
• Topology	VC-X	Flexible to add ports
• Physical media	VC-X	Fiber
• Console/Workstations	E-2C ABL E-6U JSTARS AACC JACE	69+ Workstations, 12 Gbps max
• Video broadcast (NTSC)	VC-X	120 Mbps
• High definition (HDTV)	VC-X	1500 Mbps
• Image	E-6U	680 Mbps
• Sensor data	JACE	24 Sensor, 1.3 Gbps
• Optical storage	E-6U	1-100 TB
• Legacy LAN	VC-X	TCP/IP over ATM
• 1553 • 1553B	E-6U ABL	4 1553 Bus, 4 Mbps
• Ethernet	E-6U ABL	8 Ethernet, 155 Mbps
• FDDI	E-6U	8 FDDI, 800 Mbps
• SONET OC-1	JACE	8 OC-1, 415 Mbps
• SONET OC-3	JACE	16 OC-3, 2.5 Gbps
• Data rate - per path	JAST	2.5 Gbps
• Data rate - aggregate	JAST	100 Gbps
• Data integrity - streaming	JAST	BER = 1×10^{-7}
• Data integrity - packets	JAST	BER = 1×10^{-10}
• Packet size	JAST	unlimited
• Latency (per path)	JAST	10 µs
• Blocking	JAST	nonblocking

Network Parameters	Platform	ISSN Capability
2. **Network Operation**		
• Network control	VC-X	Redundant control
• Centralized,distributed	VC-X	Distributed
• Interoperability	VC-X	Open system architecture for multivendor compatibility
• Security	VC-X JAST	Multi-level security network
• Reconfigurability	VC-X	Reconfigurability of data comm resources
• Scalability (BW, service)	VC-X JAST	Upgradeable to add new functions easily without a need for redesign
• Reliability (fault tolerant or redundant system)	JAST	Redundant system, other programs?
• Maintainability	VC-X JAST	Built-in integrated diagnostics
3. **Others**		
• Environments (EMI, EMC)	JAST	High isolation
• Manufacturability	JAST	COTS software and hardware
• Multivendor compatibility	VC-X JAST	unlimited

Table 2.2.1. Network Requirements for Advanced C4I Aircrafts

3.0. ARCHITECTURE AND TECHNOLOGY TRADE

3.1. Trade Process

The architecture and technology trade is an important process for validating the employment of ATM into advanced C4I platforms. We adopted a guideline which follows commercial trends as much as possible unless they directly conflict with C4I mission readiness. This will maximize COTS components and ensure interoperability between commercial and military systems. The network is segmented into the backbone and the subnetwork, which will frequently have different design requirements. The arrangement facilitates the trade process and follows the trend of

commercial systems. The backbone consists of relatively large switches interconnected by large data pipes. The subnetwork provides the final connectivity from the backbone switches to the endusers. The subnetwork may be a simple point-to-point connection or a separate network solution. The backbone and the subnetwork sections may or may not have common solutions. Solutions using high speed networking technologies (e.g., FDDI, ATM) to provide connectivity to the desktop (i.e., subnetwork) does not have universal support in the commercial networking business. ATM, on the other hand, is generally accepted as the solution for the future backbone of the network. If different network technologies were chosen for the backbone and the subnetworks, the cost of bridging the two solutions would have to enter into the final trade/selection process.

A common trade had to be completed for the backbone and subnetwork due to resource limitations. Significant differences are noted.

3.1.1. Trade Template

Table 3.1.1 and 3.1.2 are the templates of the C4I network trade. The template is derived from a trade procedure used within the Boeing Company. It requires the user to break down the rationalizations for the downselection process. The process helps clarify the limitations of each solution. The depth of the present rationale and scoring process is limited to the scope of the present contract.

The table's primary components are the network elements, their scoring weights (relative importance), their options, the network parameters used to score the options, the final total score, followed by the concluding downselected solution(s). It is frequently difficult to complete an independent trade for each network element. There are solutions for different elements that will be interrelated or in direct conflict. These potential conflicts are resolved by weighting the elements.

The network parameters are segmented into cost, risk and interface issues. The options are scored based on these issues. Cost is broken down into acquisition, installation, maintenance, and operation costs. Risk is segmented into commercial availability, development and production risks. The interface parameter is segmented into performance, reliability, scalability, reconfigurability, and management capabilities.

The elements are grouped as either architecture or technology trade issues. The following elements with their options form the basis for the backbone and subnetwork architecture trades.

<u>Architecture Trade:</u>

- System: Integrated vs. Federated
- Data Format: Analog vs. Digital
- Physical Topology: Centralized or Distributed

- Logical Topology: Active Star, Passive Star, Bus, or Ring
- Network Type: High Speed LAN or Switched Legacy LAN
- Redundancy: Redundant switches or redundant cableplant
- Switching Type: Matrix, Bus or Software
- Cableplant: Multi-mode, single-mode fiber, Coaxial, Shielded Twisted Pair (STP), Unshielded Twisted Pair (UTP), RF or IR

Technology Trade:

- Network Technology: ATM, Ethernet, Fast Ethernet, Token Ring, FDDI, Switched Ethernet, or Fast Switched Ethernet
- Transport Protocol: 25 Mbps ATM, 45 Mbps DS-3, 155 Mbps OC-3, 622 Mbps OC-12, 1.2 Gbps OC-24, or 2.4 Gbps OC-48

3.1.2. Network Scoring

Each option is given an unweighted score (unwt on table) for each parameter. The options are given a score of 1 through 3 for each network parameter. Parameters having no significant input receive a middle score (2). A significant disadvantage or advantage for selecting a particular solution receive a low (1) and high (3) score, respectively. These unweighted values are multiplied by the weights (relative importance in the network design process) of the network parameters to give the weighted scores. The option with the highest total weighted score becomes the solution recorded in the final column of the trade table. The weights for the network parameters and the elements are explained in the following two sections.

3.1.3. Network Parameters

The weighting for the network parameters ranges from 1 through 10 to indicate the network parameter's level of importance in the trade process (1 being the lowest and 10 the highest). The general guideline for weighting is as following: The lower values minimally impacts the overall final solution and has not been called out as an important issue by a program or customer. The weight 5 is given to an issue that is not that important for architecture or network design but is specified by the customer as a concern. The weight 10 is given to parameters that significantly impact the network design and has been called out as an important concern by the customer.

Explanations for Network Parameter Weightings:

Cost/Acquisition: Cost of acquiring the network/communication components
Weight=3
The customer generally calls this out as an important issue in today's budget conscious environment. However, the network cost will be relatively low compared to the overall cost of C4I development mitigating its importance.

Cost/Installation: The one-time cost of installing the network onto the aircraft during manufacturing/integration process of the C4I platforms.
Weight=3
There will be relatively few installations comparing with commercial markets and the process will be a relatively small part of the overall high value C4I manufacturing process. However, the customer has concerns about the reduction of the overall cost.

Cost/Maintenance: The recurring cost to the customer to maintain the network.
Weight=8
Customer is likely to emphasize the design of a low-maintenance airplane to reduce their long-term labor cost and downtime.

Cost/Operation: The recurring cost of operating/running the network.
Weight=8
It is important to design a low operational cost airplane to reduce recurring expense and to minimize management manpower requirements.

Risk/Product Availability: Availability of existing COTS or MILSPEC products that may or may not be suitable for the aircraft environment
Weight=3
Again, the customer is exerting pressure to use available commercial products (COTS) to reduce cost. Minimizing MILSPEC custom parts is a desirable trend. It is important to take advantage of commercial resources to maximize the capability of the system. Interoperability with commercial systems will be easier. Parts will be relatively available for manufacturing and maintenance. However, since this design is for an advanced C4I platform, the emphasis on present COTS availability will be reduced.

Risk/Product Development: Risk of developing/customizing product to make it suitable for aircraft environment.
Weight=2
Since this is a design for future advanced C4I platforms this is a less important issue. There is not an immediate delivery date. On the other hand, it is necessary to make sure that architectures/technologies are not selected that have intrinsic problems with an aircraft's environment, etc.

Risk/Production: Risk of having a build component that does not lend itself easily to a manufacturing process.
Weight=1
This network will be for future C4I applications and will be low volume by commercial telecommunication standards, so a customized specialty production process would not be a large problem.

Interface/Performance: Apparent performance to the enduser. Quality of data, video, voice quality. Connection setup success rate.
Weight=10
This is the most important issue which directly impacts the user of the system. Direct interface between customer and network/communication system. C4I platforms by their nature require very high performance network/communication systems in order to perform their functions with maximum utilization.

Interface/Reliability: An overall description for MTBF and maximum size of the network that can be taken down with a given failure. Impact of failure on performance.
Weight=8
The cost of a C4I mission is high so the reliability of each subsystem is very important to ensure mission success.

Interface/Scalability: The range of traffic load and number of endusers the network can serve.
Weight=7
Mission demands are changing rapidly with technology thus the customer requires flexibility. This includes scalability to add workstations, sensors, off-board communication link interfaces, etc. The manufacturer wants scalability so they can install the system into varying platforms with different load demands. This will increase the C4I network/communication "market" thereby reducing acquisition cost.

Interface/Reconfigurability: The ease with which the network can be changed to handle different endusers and different enduser/node locations on the aircraft.
Weight=7
Similar reasoning given for Scalability. The demands are changing rapidly with technology thus the customer will require reconfigurable networks to allow for different missions using the same C4I platform. This includes reconfigurability to change locations of workstations, sensors, etc. on a given aircraft. The manufacturer wants reconfigurability so they can install the system into platforms with different mission requirements (i.e., varying load demands and physical layouts). The more platforms sold, the cheaper the network system.

Interface/Management: The service that configures and monitors the network.
Weight=3
The demands are changing rapidly as is technology thus the customer requires a management system that can handle varying configurations. The customer requires a management system that can handle security issues and access control. The manufacturer wants scalability so they can install the system into platforms with different load demands. This also will require a flexible management system. The score is reduced because the information collected for this network parameter is presently minimal.

3.1.4. Network Elements

This section provides the rationale behind the assigned weights for the network elements. It is used to settle potential conflicts between incompatible solutions of different elements. The weighting ranges from 1 through 3 (in order of increasing importance) for the network. The weighting of the network elements is important because it indicates the relative importance of the different network elements making up the trade process.

<u>System</u>: Integrated or Federated
Weight=3
Trade between integrated and federated networks is an important issue as this network design is for advanced C4I applications and advanced commercial systems capable of handling multiple media. Therefore, the emphasis is on the system integration in order to reduce cost and to improve reliability.

<u>Data Format</u>: Digital or Analog
Weight=3
Will the transmission of data use digital or analog signals? The future systems must be compatible with future commercial transmission systems which will be carrying digital video, voice and data over B-ISDN/ATM. Noise immunity and data processing capabilities will be enhanced with a complete digital distribution system.

<u>Physical Topology</u>: Centralized or Distributed
Weight=2
The physical layout of the network on the C4I platform is of medium importance to the customer and potentially affect the manufacturability and reconfigurability but not the performance.

<u>Logical Topology</u>: Active Star, Passive Star, Bus, or Ring
Weight= 3
This is the topology of the transition connection between switch, node and users. The parameter impacts bandwidth availability which in turn impacts performance.

<u>Network Type</u>: High Speed LAN or Switched Legacy LAN
Weight= 2
This will directly impact the enduser cost and capability.

<u>Redundancy</u>: Redundant Switch or Redundant Cableplant
Weight=3
Redundancy is required to ensure no single point of failure throughout the network. This is an important issue for C4I applications since there are functions that require no single point of failure throughout the network.

Architecture Trade

				Network Parameters													
					cost				Risk				Interface				Conclusions
				Acq	Inst	Mtn	Op	COTS	Dev	Prod	Perf	Rlbty	Scale	Recon	Mgmt		
Elements	Wt	Options	Weight>	3	3	8	8	3	3	2	10	8	7	7	3	Total	Solutions
System	3	Integrated	unwt	3	3	3	2	2	1	2	3	2	3	3	3	30	Integrated
			wt	9	9	24	16	6	3	4	30	16	21	21	9	168	
		Federated	unwt	1	1	1	2	3	3	3	2	3	1	1	1	22	
			wt	3	3	8	16	9	9	6	20	24	7	7	3	115	
Data Format	3	Analog	unwt	3	1	2	2	2	2	2	1	1	1	1	1	19	
			wt	9	3	16	16	6	6	4	10	8	7	7	3	95	
		Digital	unwt	2	3	3	3	2	2	3	3	3	3	3	3	33	Digital
			wt	6	9	24	24	6	6	6	30	24	21	21	9	186	
Physical Topology	2	Centralized	unwt	2	2	3	2	2	2	2	2	2	2	2	2	25	
			wt	6	6	24	16	6	6	4	20	16	14	14	6	138	
		Distributed	unwt	3	3	2	2	3	2	2	2	3	2	3	2	29	Distributed
			wt	9	9	16	16	9	6	4	20	24	14	21	6	154	
Logical Topology	3	Active Star	unwt	2	1	2	2	2	2	1	3	3	3	1	0	22	Active Star
			wt	6	3	16	16	6	6	2	30	24	21	7	0	137	
		Bus	unwt	3	3	3	3	3	3	3	1	1	1	3	0	27	Bus
			wt	9	9	24	24	9	9	6	10	8	7	21	0	136	
		Ring	unwt	3	2	2	2	3	3	2	1	2	2	3	0	25	
			wt	9	6	16	16	9	9	4	10	16	14	21	0	130	
		Passive Star	unwt	2	1	2	2	2	2	1	1	1	2	2	0	18	
			wt	6	3	16	16	6	6	2	10	8	14	14	0	101	
Network Type	2	High Speed LAN	unwt	2	2	2	2	2	2	2	3	2	3	2	2	26	High Speed LAN
			wt	6	6	16	16	6	6	4	30	16	21	14	6	147	
		Switched LAN	unwt	3	3	3	3	3	3	3	1	3	1	2	2	30	Switched LAN
			wt	9	9	24	24	9	9	6	10	24	7	14	6	151	
Redund Measures	3	Switch	unwt	2	2	2	2	2	2	2	3	3	2	2	2	26	Switch
			wt	6	6	16	16	6	6	4	30	24	14	14	6	148	
		Cableplant	unwt	3	2	2	2	2	2	2	2	3	2	2	2	26	Cable
			wt	9	6	16	16	6	6	4	20	24	14	14	6	141	
Switch	3	Matrix	unwt	3	2	1	2	2	2	2	2	3	3	2	2	26	matrix
			wt	9	6	8	16	6	6	4	20	24	21	14	6	140	
		Bus	unwt	2	2	2	2	2	2	2	3	2	2	2	3	26	bus
			wt	6	6	16	16	6	6	4	30	16	14	14	9	143	
		Software	unwt	1	2	1	1	2	3	3	1	1	1	2	1	19	
			wt	3	6	8	8	6	9	6	10	8	7	14	3	88	
Cableplant	2	mm	unwt	3	2	2	2	3	3	3	3	3	3	2		29	
			wt	9	6	16	16	9	9	6	30	24	21	14	0	160	mm
		sm	unwt	1	1	1	2	2	2	2	3	2	3	1		20	
			wt	3	3	8	16	6	6	4	30	16	21	7	0	120	
		coax	unwt	2	2	2	2	3	2	2	2	2	2	2		23	
			wt	6	6	16	16	9	6	4	20	16	14	14	0	127	
		stp	unwt	3	3	3	2	3	2	2	1	2	1	2		24	
			wt	9	9	24	16	9	6	4	10	16	7	14	0	124	
		utp	unwt	3	3	3	2	3	2	1	1	2	1	2		23	
			wt	9	9	24	16	9	6	2	10	16	7	14	0	122	
		rf	unwt	1	3	1	2	1	1	1	1	1	1	3		16	
			wt	3	9	8	16	3	3	2	10	8	7	21	0	90	
		ir	unwt	1	3	1	2	1	1	1	1	1	1	3		16	
			wt	3	9	8	16	3	3	2	10	8	7	21	0	90	

Table 3.1.1. Architecture Trade Scoring Chart

Technology Trade

				Network Parameters													Conclusions
				cost				Risk			Interface						
				Acq	Inst	Mtn	Op	COTS	Dev	Prod	Perf	Rlbty	Scale	Recon	Mgmt		
Element	Wt	Options	Weight>	3	3	8	8	3	3	2	10	8	7	7	3	Total	Solution
Network	2	ATM	unwt	2	2	2		2	2	2	3	2	3	2	1	23	
			wt	6	6	16	0	6	6	4	30	16	21	14	3	128	ATM
		Ethernet	unwt	3	3	3		3	3	3	1	3	1	2	3	28	
			wt	9	9	24	0	9	9	6	10	24	7	14	2	123	
		Fast Ethernet	unwt	2	2	2		2	3	2	1	2	1	2	2	21	
			wt	6	6	16	0	6	9	4	10	16	7	14	6	100	
		Token Ring	unwt	2	2	2		2	2	2	1	2	1	2	2	20	
			wt	6	6	16	0	6	6	4	10	16	7	14	6	97	
		FDDI	unwt	2	2	2		2	2	2	2	2	2	2	2	22	
			wt	6	6	16	0	6	6	4	20	16	14	14	6	114	
		Switched Ethernet	unwt	3	3	3		3	3	3	1	3	1	2	3	28	Switched
			wt	9	9	24	0	9	9	6	10	24	7	14	9	130	Ethernet
		Fast Switched	unwt	3	2	2		2	2	2	1	2	1	2	2	21	
		Ethernet	wt	9	6	16	0	6	6	4	10	16	7	14	6	100	
Transport	2	25mbps ATM	unwt	3	3	3	2	3	3	3	1	3		3		27	
Protocol			wt	9	9	24	16	9	9	6	10	24	0	21	0	137	
		45mbps DS3	unwt	3	3	3	2	3	3	3	1	3		3		27	
			wt	9	9	24	16	9	9	6	10	24	0	21	0	137	
		155mbps OC3	unwt	3	3	3	2	3	3	3	2	3		3		28	
			wt	9	9	24	16	9	9	6	20	24	0	21	0	147	155mbps
		622mbps OC12	unwt	1	1	1	2	3	1	1	3	1		1		15	
			wt	3	3	8	16	9	3	2	30	8	0	7	0	89	
		1.2Gbps OC24	unwt	1	1	1	2	1	1	1	3	1		1		13	
			wt	3	3	8	16	3	3	2	30	8	0	7	0	83	
		2.4Gbps OC48	unwt	1	1	1	2	3	1	1	3	1		1		15	
			wt	3	3	8	16	9	3	2	30	8	0	7	0	89	

Table 3.1.2. Technology Trade Scoring Chart

Switching Type: Hardware (e.g., matrix, bus) or Software
Weight=3
Selection between SW and HW based technologies could be an important issue as it may directly impact performance of the network.

Cableplant: Fiber (MM, SM), Copper (Coax, STP, UTP), or Wireless (RF, IR)
Weight=2
Selection of the physical medium for the connecting cables does not directly impact the customer via application performance, thus it is not of high level importance. It may impact manufacturing, reconfigurability, and reliability.

Network Technology: ATM, Ethernet, Fast Ethernet, Token Ring, FDDI, Switched Ethernet, or Fast Switched Ethernet
Weight=2
This switching protocol is a fairly low level aspect of the network design, therefore it does not deserve the highest ranking.

Transport Protocol: 25 Mbps ATM, 45 Mbps DS-3, 155 Mbps OC-3, 622 Mbps OC-12, 1.2 Gbps OC-24, and 2.4 Gbps OC-48
Weight=2
The protocol used to transmit the data is a fairly low level aspect of the network design and thus it does not deserve the highest level of weighting.

3.2. Architecture Trade

Table 3.1.1 and 3.1.2 show the results of the architecture and technology trade documented on the trade template. The following sections provide the rationale behind the scores.

3.2.1. System: Integrated or Federated

The scoring was based on designing a future C4I aircraft where developmental risk could be taken. The network technology will not be delivered within the next few years. The technology does not need to be available off the shelf, today. There does need to be a sufficient level of commercial interest to drive development within the next few years. Scoring will be similar between the backbone and the subnetwork.

The primary driver for integrating systems, including networks, is to save weight, space and utilities through the sharing of resources. The benefits are of particularly high value on aircrafts. More users will share a common communication resource. Fewer dedicated resources including components and cableplants means savings during design, manufacture, operation and maintenance of the system. A higher level of modularity/commonality can be achieved if common enduser/nodes are used

throughout the aircraft. This reduces the unique parts count and enhances reconfigurability if all functions have the same interface for the data networking needs.

Costly software will have to be written for the multipurpose/multitasking integrated system, complicating the testing/certification procedure. If different reliability and/or security levels are handled over a common network, robust protective measures will have to be inserted. A given failure on the integrated network impacts a large number of applications. Integration of networks on an aircraft is an immature concept. Federated solutions have a large experience base and can be optimized for the unique requirements of particular functions.

<u>Cost/Acquisition</u>: Integrated systems will require fewer unique components and cableplant. The volume of parts on a given C4I platform will also be reduced because more functions will share fewer network resources. This will tend to reduce the acquisition cost for the aircraft. Presently, the specific part may cost more because of relative complexity, but this will change as the commercial market pursues multimedia/ATM for WAN/LAN to the desktop, etc. which will rapidly bring down network prices. Software cost will drop with volume.
Integrated =3; Federated=1

<u>Cost/Installation</u>: Fewer unique components and cableplant with the integrated system results in smaller stock inventory. Shared resources mean fewer parts to install during the aircraft manufacturing process. Common interfaces on the aircraft for different functions at the enduser will simplify installation. Different functions can have identical connectors.
Integrated =3; Federated=1

<u>Cost/Maintenance</u>: An integrated system can share an automated maintenance check procedure through the network manager. This will allow a common vantage point to review maintenance problems. Fewer unique components and cableplant results in maintaining a smaller inventory and maintenance expertise base. Shared resources suggests fewer parts to inspect during the life of the aircraft. The disadvantage is that the parts will be relatively complex, but they will have embedded maintenance capabilities as compensation.
Integrated =3; Federated=1

<u>Cost/Operation</u>: The fact that the network is integrated or federated will, in a well designed system, be transparent at the higher operating layers. There is no apparent advantage.
Integrated =2; Federated=2

<u>Risk/Availability</u>: Today, the practical experience base for developing integrated networks on aircraft is relatively low, increasing the availability risk. There is likely to be mature commercial products available in ~10 years distributing large flows of

complex mixed media information. Customization will be required to improve the reliability and environmental operating range to meet C4I aircraft specifications. The commercial mixed media distribution industry is developing rapidly, mitigating risk.
Integrated =2; Federated=3

Risk/Development: An integrated solution will require development of relatively complex overhead (signalling, management), resulting in more lines of code which has always been a difficult task for airborne systems.
Integrated =1; Federated=3

Risk/Production: Integration of functions onto one network will increase the complexity of the network components, increasing the complexity of the production process. Federated systems are relatively simple solutions designed for specific tasks. However, there is a strong commercial market push for BISDN service, which will directly benefit integrated networks developed for C4I missions.
Integrated=2; Federated=3

Interface/Performance: Integration of video, voice and data (different applications/functions) onto one network generally involves sacrificing performance they would have enjoyed on media specific networks (i.e., federated solutions). This sacrifice in performance will probably become insignificant over time for most applications due to strong commercial development activity. However, there may be unique functions (control, etc.) that have very stringent performance requirements (delay, jitter, etc) making them poor candidates for depending on an integrated network solution. Macroscopically, the reduced space, power, heat load and weight will improve the overall performance of the aircraft. Presently, the federated solutions are better but in the future the integrated solution will provide overall C4I platform performance superiority.
Integrated=3; Federated=2

Interface/Reliability: The larger number of potentially disruptive endusers on an integrated system will have a negative impact on reliability. The network manager/architecture will be designed to reduce the impact a particular enduser could have on network traffic. Shared resources implies more potential for wide spread service disruption with a component failure. However, providing redundancy will be much more efficient using shared resources. Also, the network manager will have more options to correct or compensate for problems using shared resources. These factors will mitigate the reliability disadvantage of integrated solutions. However, if the maximum level of reliability available is required, the dedicated federated system is the only solution. The extreme case is an individual point to point network solution for every function on the aircraft.
Integrated=2; Federated=3

Interface/Scalability: Federated solutions involve multiple unique networks satisfying specific functional requirements. Integrated solutions involve fewer unique networks each having the flexibility to handle multiple functions. This flexibility lends itself to scalability in bandwidth, switching capacity, etc. Future upgrades on a C4I platform using integrated systems will be less costly because there are fewer unique components. However, if only one particular function requires a performance upgrade it will be easier to upgrade its federated network.
Integrated=3; Federated=1

Interface/Reconfigurability: The reconfigurability of the integrated system will be superior because it will not be application/function specific. Universal connections will be placed throughout the aircraft. A specific application with any type of media (video, voice and data) or function will easily connect to the universal interfaces at any location of the network (aircraft). An enduser with a federated interface will only be able to connect to its federated network solution.
Integrated=3; Federated=1

Interface/Management: Federated system management complexity increases approximately linearly with the number of application/networks. Management complexity of integrated systems increases sublinear with the number of applications.
Integrated=3; Federated=1

3.2.2. Data Format: Analog or Digital

The commercial market will be converting audio, video and data all to a digital format over the next 10 years (CD audio, compression, HDTV, etc.). Analog is being phased out certainly in the time duration of a new C4I platform's lifespan (~30 years). Compatibility and seamless connectivity to the commercial world requires a compatible digital military system. Digital audio, video and data format allows common interface ports, which is beneficial to reduce cost and improve configurability, etc. Current analog audio, video and data have typically unique interfaces. Data does not have a good analog solution which provides another reason for the early demise of analog solutions. State-of-the-art information processing requires digital formatted data. Multimedia and compression require digital formats. A military C4I platform's primary task is to absorb, process and distribute information. The platforms will benefit using the digital format.

If processing requires a digital format, there is not much reason to use an analog format for intra-aircraft transmission. An analog format is relatively spectrum efficient but is susceptible to noise. Spectrum limited transmission links like satellite to ground do benefit using analog mode transmission. C4I onboard hardwire transmission capacity will be relatively abundant, so analog data will not be a desired format for onboard transmission. It performs relatively poorly in electronically hostile environments.

Cost/Acquisition: Analog has a large market base and is intrinsically cheaper to manufacture. The digital market base is building up rapidly.
Analog =3; Digital=2

Cost/Installation: Analog has unique solutions for different media. Digitalization helps enable integration. Digitalization allows one common connection containing audio, video and data to be used for multiple functions.
Analog =1; Digital=3

Cost/Maintenance: Digital systems have embedded self monitoring capability. Digital enables integration which reduces part count. However, analog components are simpler.
Analog =2; Digital=3

Cost/Operation: Digital enables integration which reduces the number of components required for the tasks, which should reduce the cost of operation.
Analog =2; Digital=3

Risk/Availability: Analog has the largest experience base, but there is a rapidly growing market base for digital systems.
Analog =2; Digital=2

Risk/Development: Analog video and audio has a larger experience base, reducing its implementation risk. However, there is considerable effort in high resolution imagery in the form of HDTV, which is a digital format. This is one example of digital processing of information that is being implemented in the commercial sector. This sector is growing rapidly, which will reduce development risk for implementation of digital solutions. Ongoing commercial development of multimedia products will reduce developmental risk.
Analog =2; Digital=2

Risk/Production: There will be lower risk producing custom digital components. A large custom IC manufacturing base produces application specific components.
Analog =2; Digital=3

Interface/Performance: Digital systems have superior quality audio (CD), video (HDTV) and data. In addition, the digital option is less susceptible to noise.
Analog =1; Digital=3

Interface/Reliability: Analog systems will be more susceptible to interference, noise, and loose connectors than digital systems. They also have larger S/N requirements.
Analog =1; Digital=3

Interface/Scalability: Digital systems are more scalable. They enable convenient switching of multiple data sources on a single cable. They also allow more efficient utilization of data transmission and storage resources due to compression. It is convenient to route signaling overhead along with data in digital systems. These features enhance the scalability of the system to handle more users having unique data requirements.
Analog =1; Digital=3

Interface/Reconfigurability: Digital networks transparently route reconfiguration related signaling overhead along with the data. Digital data lends itself to switching multiple data sources from a single port to multiple users which is an important feature for reconfigurability.
Analog =1; Digital=3

Interface/Management: It will be easier to manage digital systems because of the ease of transmitting parallel overhead.
Analog =1; Digital=3

3.2.3. Physical Topology: Centralized or Distributed

Concentrating (centralizing) functions results in failures potentially impacting larger portions of the system compared to distributed designs. It also goes against the commercial trend to distribute network resources. Space in central locations on aircraft (i.e., electronics bays) are already at a premium so it would be advantageous to place network components in relatively under-utilized locations.

The primary driver for centralizing networks is to simplify systems. The bulk of the system can be situated in fewer, larger, easily accessible (for maintenance) centralized enclosures. The enclosures can also be environmentally controlled.

Cost/Acquisition: Concentrating the components requires fewer enclosures. The enclosure can be environmentally controlled so that simpler, cheaper cableplant can be used to interconnect components within the cabinets. Environmentally hardened cableplant may only have to be used external to the cabinet. More backbone cabling would have to be used for distributed systems. The level of resource sharing could be increased to reduce cost.

A centralized architecture will require much more subnetwork cabling and longer unshared routes between the server and endusers. The commercial tendency is to use distributed schemes. This trend will reduce the cost because of the commercial manufacturing base. It wouldbe difficult to find significant localized space in the electronics bay.
Centralized =2; Distributed=3

Cost/Installation: Installing parts in fewer, easier access locations/cabinets (electronics bay, headend cabinet) with the centralized system would simplify the installation process. Relatively standard cabling may be used within the environmentally controlled enclosure, simplifying the installation process. However, electronics bays are short of space and distributed physical topologies allow components to be placed in areas where there is less of a premium on space. The final solution depends on the particular C4I applications. For example, on a UAV, it probably does not make sense to distribute. On a large AWACS platform, however, with an already overcrowded electronics bay, it may be advantageous to distribute to the relatively sparsely populated overhead sections. Centralized architectures will probably require more cabling which will increase installation cost.
Centralized =2; Distributed=3

Cost/Maintenance: Fewer enclosures simplifies access for maintenance.
Centralized =3; Distributed=2

Cost/Operation: Operation cost should be transparent to the fact that the system is distributed or centralized.
Centralized =2; Distributed=2

Risk/Availability: The commercial trend is for LAN networks to be physically distributed in design. However, there are commercial solutions collapsing the primary routing component of the network. This forms a physically centralized backbone for a LAN without changing the functionality of the system.
Centralized =2; Distributed=3

Risk/Development: It is generally more complex to develop a distributed network. The commercial trend is for LAN networks to be physically distributed in design. There will be a larger selection of distributed mode products.
Centralized =2; Distributed=2

Risk/Production: The centralized system will take advantage of less external cabling (backbone) and components due to localized enclosures. However, there will be more external cabling, which mitigates the reduced backbone cabling requirement.
Centralized =2; Distributed=2

Physical Interface/Performance: There should be little variation in performance between the two options.
Centralized =2; Distributed=2

Physical Interface/Reliability: Centralized system components should have better protection within their enclosures. However, a problem at the location of a centralized system will impact a larger portion of the network. Reliability is improved commercially by using distributed solutions.

Centralized =2; Distributed=3

Physical Interface/Scalability: The relative accessibility of the centralized system lends to module upgrade. However, the commercial LAN trend is to scale distributed architectures.
Centralized =2; Distributed=2

Physical Interface/Reconfigurability: An aircraft is typically divided into zones, which lends itself to distributed systems. This may simplify reconfiguration between the zones.
Centralized =2; Distributed=3

Physical Interface/Management: Centralizing the control of a network will simplify management procedures. However, aircrafts are often divided into zones, which lends itself to distributed management.
Centralized =2; Distributed=2

3.2.4. Logical Topology: Active Star, Passive Star, Bus, or Ring

The scoring is based on a relatively small area application requiring a multimedia capable network. The subnetwork will require network access points and flexibility to handle changes in mission requirements. The backbone configuration will remain relatively fixed after installation.

An active star has a radial topology for the cableplant, with active switching at the center, enabling the transmission of connection oriented dedicated baseband data to the node/enduser. This topology is similar to that used by the Telecommunications industry for their large area communication systems to deliver POTS and ISDN service.

The passive star has a similar cableplant but uses passive signal splitting instead of active switching at the center. The topology was used for the Fiber Optic Data Bus program which developed a network to transmit control and sensor data for satellite applications. This arrangement is commonly used for broadcasting broadband video. The most visible commercial use of the topology is by the CATV industry, which recently is attempting to expand the system to deliver interactive mixed media services.

The bus is a connectionless network shared by multiple users. It is the most pervasive local area office network topology in use today. The ring topology connects nodes to form logical rings and uses tokens for regulating access to the network. This avoids potential network contention problems inherent with shared bus topology. Vendors using the final two topologies are just beginning to demonstrate mixed media products. The topologies will be inherently less scalable due to their non-connection oriented architectures. The passive star will be difficult to make interactive without incorporating a second network. The active star shows the most promise for scalability

and is being developed today specifically for seamless transmission of mixed media over the LAN and WAN. A virtual connection-oriented network technology (ATM/SONET) will be used. The active star solution can emulate connectionless protocols over the connection-oriented protocol (ATM). This will allow the technology to take advantage of existing TCP/IP applications. Another active star solution is switched Ethernet with multiple ports delivering Ethernet to endusers. A high capacity port delivers a fast Ethernet, FDDI or ATM port for the server or backbone switch. This would provide a switched connectionless service over an active star topology. The cableplant would be the same with either connection or connectionless switching technologies, which is an advantage of the active star topology. It allows a customer to start with relatively mature, inexpensive, proven, switched legacy LAN architectures. The customer can, at a later date, migrate towards ATM/SONET by replacing switching/node components without changing the cableplant.

<u>Cost/Acquisition</u>: The active star connection-oriented topologies will be well on its way to dominating the mixed media local area market in the form of switched legacy LANs and/or ATM/SONET during the life cycle of a new C4I platform. There are already switched Ethernet/FDDI products (Southpointe, 3COM, Cabletron, etc.) and 25 Mbps ATM active star products available @ ~ $500 per NIC that can handle video, voice and data (First Virtual Inc.). These networking technologies use the active star topology.

Today, the most pervasive and thus cheapest topologies for local area applications are bus or Token Ring in nature. However, their connectionless protocols limit their capacity. They will probably not even be sufficient for the feeder portion of the network. They will not be able to serve out a typical C4I platform's life expectancy. This trade is weighted toward availability over the duration of a new C4I aircraft. Active star components will be very competitively priced.
Active Star =2; Bus=3; Ring=3; Passive Star=2

<u>Cost/ Installation</u>: This is an active star's primary disadvantage. The aircraft industry is familiar with the daisy chain and bus topologies. They distribute entertainment programming for the passenger and control/sensor information. This topology lends itself to a modular cableplant. Sections of cable can be extended or removed as stations are added or removed from the aircraft. This reduces the unique lengths/types of cable required for the aircraft. This gives an edge to the bus and ring topologies which are physically similar. The ring topology has more cabling and more complex components to deal with during installation. If many nodes are being served, the star topology will tend to have multiple transmission lines (glass or copper) within a cable (bulk). This will be harder to install, require multiple pin bulkhead connectors and have unterminated connections. It does not efficiently lend itself to a modular system especially over larger number of nodes. A passive star will have fewer and simpler components to install compared to the active star.

An active star by nature does not share its cabling resources within the feeder portion of the network, which means more parts to install. This will be most disadvantageous for the subnetwork with its many destinations relative to the backbone network.
Active Star =1; Bus=3; Ring=2; Passive Star=1

<u>Cost/Maintenance</u>: The bus will be the simplest to maintain because it has the least total number of transmission lines (fiber or copper), the simplest connectors (fewer pins for bulkhead connectors) and is the most modular. The ring topology is again slightly more complex, adding to maintenance. This is followed by the passive star and the active star. However, automated self-maintenance will be simpler with the active star topology because of its tendency toward connection-oriented baseband operation. On the other hand, it may be easier to monitor a common connectionless network operating in broadcast mode.
Active Star =2; Bus=3; Ring=2; Passive Star=2

<u>Cost/Operation</u>: The bus topology will have fewer unique parts, so the overall operating cost should be lowest. The active star option is relatively complex and requires more cabling. This may increase operating costs.
Active Star =2; Bus=3; Ring=2; Passive Star=2

<u>Risk/Availability</u>: The bus and ring are presently the most pervasive topologies in use. They provide the least risk from an architectural information availability aspect. There is a large available commercial base of applications designed to work over these protocols. A few vendors have demonstrated multimedia services over the bus. This is accomplished despite its limitations as a shared contention-based connectionless service (Southpointe). There are no known vendors with ring based products delivering multimedia services. The active star topology is moving quickly as a multimedia delivering topology, with switched Ethernet and the more advanced ATM/SONET services. The passive star will not be a serious contender for commercial local area network applications, unless CATV markets their future solution for delivering interactive services over cable.
Active Star =2; Bus=3; Ring=3; Passive Star=2

<u>Risk/Development</u>: The bus and ring topologies are low risk because they are well established in local area office network applications and have already been installed in the form of daisy chains and buses across the aircraft and therefore have been through aircraft application certification procedures. The star would be new for aircraft applications and would require more complex cabling and connectors, increasing the developmental risk. However, there is considerable activity in switched routing products (ATM, switched Legacy LAN) that will be consistent with the active star topology. The passive star option has the highest risk because CATV, a wide area product video provider, is the only vendor developing the topology. They are unlikely to develop and market the option for local area office applications.
Active Star =2; Bus=3; Ring=3; Passive Star=2

Risk/Production: The bus and the Token Ring technologies have the most modular cableplant and therefore are the lower production risks. Passive star has simpler components than the active star making it relatively easy to produce.
Active Star =1; Bus=3; Ring=2; Passive Star=1

Interface/Performance: The bus will have contention problems when excessive traffic flows are encountered. This is true for the backbone and the subnetwork as applications become more sophisticated. C4I applications will not tolerate performance or resolution loss resulting from compression. So the data rate requirements will increase. The performance of the ring topology is improved due to its more sophisticated network access management. The active star will have the optimum performance due to its connection oriented baseband nature. Setting up and maintaining connections on demand is optimal because of its connection oriented nature. It will be difficult for the passive star network to provide integrated interactive service due to the signal splitters.
Active Star =3; Bus=1; Ring=1; Passive Star=1

Interface/Reliability: Due to the connection-oriented nature of an active star cableplant there is less likelihood of an individual failure bringing down a large portion of the network relative to the bus or ring. The active and passive star's topologies are more complex than the bus and ring topologies. This added complexity results in more chances for individual physical failures. The active star has more complex components than the passive star option. Similarly, the ring is more complex than the bus. The ring is superior to the bus in being able to compensate for a break, however.
Active Star =3; Bus=1; Ring=2; Passive Star=1

Interface/Scalability: The active star is the most scalable topology because it provides a dedicated virtual connection (data pipe) to each enduser/node. Each of the connections only has to transmit data to the particular enduser. It is not a shared resource in this aspect. The other topologies either share the transmission lines among many nodes (bus and ring) or transmit multiple channels to each user (passive star). The schemes will have much higher data rates on the lines and therefore cannot handle an increase in bandwidth per enduser or total number of endusers as well as the active star scheme. The ring will be slightly better than the bus due to its more sophisticated access scheme. The passive star option does not easily allow an integrated solution for interactive services. It is difficult to provide duplex connections.
Active Star =3; Bus=1; Ring=2; Passive Star=2

Interface/Reconfigurability: The shared network topologies (bus and ring) are most physically reconfigurable because modular cable sections can be added or subtracted from the network relatively easily to service new configurations of enduser/nodes. The bus is easier than the ring because no return connection is required. The active and passive star options are not sharing their cableplant resources among endusers. This

will complicate reconfiguration of the network. A dedicated cable is provided to each enduser from a switch. This is unlike the bus or ring where a number of endusers can be configured to each cable length from the switch.
Active Star =1; Bus=3; Ring=3; Passive Star=2

Interface/Management: Not Available
Active Star =N/A; Bus=N/A; Ring=N/A; Passive Star=N/A

3.2.5. Network Type: High Speed LAN or Switched Legacy LAN

This issue involves deciding whether to use a high speed network technology or switched LAN technology to provide connectivity all the way to the enduser (desktop). The desktop operating system must support the new high speed networking technology. High speed LAN network interface cards (NICs) must be commercially available. In the case of C4I platforms being upgraded, are the NICs already on the enduser? If not, how much will it cost to replace them? Can the existing cableplant be leveraged? Does the internal staff or integrator fully understand the new technology? These questions primarily relate to the subnetwork, but for small area C4I platforms (eg., UAV), switched legacy LANs may also be used for the backbone.

Cost/Acquisition: The Switched Legacy LAN solution is cheaper than the High Speed LAN solution. A typical Legacy LAN switch is ~$5-10K compared to $30K for the typical ATM switch. Actually, First Virtual Incorporation is now selling a 25 Mbps ATM switch for ~$5K, so there will be aggressive pricing to decrease the cost of High Speed LAN options. However, the 25 Mbps standard is not universally embraced. Cost savings are not necessarily realized if a switched LAN subnetwork must interface with a connection-oriented High Speed LAN backbone such as ATM/SONET.
High Speed LAN =2; Switched Legacy LAN=3

Cost/Installation: Installation cost should be similar. Both are just black boxes with similar connections to installers. High Speed LAN technology will tend to have higher data rates, that require more complex, expensive connection and cabling technologies.
High Speed LAN =2; Switched Legacy LAN=3

Cost/Maintenance: A switched Legacy LAN is simpler and is based on a more pervasive technology and experience base. This results in lower maintenance costs. This advantage will decrease slowly over time.
High Speed LAN =2; Switched Legacy LAN=3

Cost/Operation: A switched Legacy LAN is simpler and is based on a more pervasive technology and experience base. This familiarity should result in lower operational costs.
High Speed LAN =2; Switched Legacy LAN=3

Risk/Availability: Presently, the availability of switched legacy LAN systems is much greater than High Speed LAN technologies. This is true when factoring in the availability of applications optimized for the protocol. This will become less true with more product deployment of High Speed LAN technologies and applications which will happen over the next 10 years.
High Speed LAN =2; Switched Legacy LAN=3

Risk/Development: The technologies are both available. However, it will be easier to customize and certify the Switched LAN technology because of it's lower rates which allows for relatively rugged connectors, etc.
High Speed LAN =2; Switched Legacy LAN=3

Risk/Production: It will be easier to manufacture Switched LAN technology because of its lower data rates, which allows for relatively simple and rugged components.
High Speed LAN =2; Switched Legacy LAN=3

Interface/Performance: A solution incorporating Switched Legacy LAN will not handle the data load of the backbone. The subnetwork will also potentially require high data rate capacity as future endusers may require on the order of 100 Mbps, which would exceed the capability of Switched Legacy LAN options. This will especially be true if there is considerable imagery being transmitted where compression is avoided to minimize loss and delay. High resolution and immediate feedback will be important for many C4I applications.

A legacy switch with a fast Ethernet or FDDI port would be an interim solution. The switched legacy LAN technology presently has a much larger application base, so the effective performance to the enduser may be similar or even better today. Presently, the majority of applications are optimized to run over the legacy LAN. Therefore, High Speed LANs are often not delivering performance gains to the individual enduser using these applications. Switched Legacy LAN options will eventually demonstrate severe performance limitations resulting from the 3-8 Mbps throughput and the connectionless protocol. Performance gains with the High Speed LAN options will be observed once applications are designed to take advantage of high data rate capacity.

This network trade process is for future advanced C4I applications, so the potential of High Speed LAN technologies will be emphasized. If the network were to be inserted onto a C4I platform within the next 5 years, the risk is high that High Speed LAN options will not be superior and may even be inferior to Switched Legacy LAN performance.
High Speed LAN =3; Switched Legacy LAN=1

Interface/Reliability: A switched Legacy LAN is simpler and is based on a more pervasive technology and experience base, so it should be the relatively reliable system.
High Speed LAN =2; Switched Legacy LAN=3

<u>Interface/Scalability</u>: The scalability of the Switched LAN system is very limited compared to the High Speed LAN technology. This is the whole basis for the latter technology's existence. Today's switched legacy LAN is limited to 3-8 Mbps to the enduser. However, the aggregate switching capability is high.
High Speed LAN =3; Switched Legacy LAN=1

<u>Interface/Reconfigurability</u>: The connectors and components will be relatively rugged with the Switched LAN technology, making it physically easier to reconfigure. But the High Speed LAN will handle a larger variety of media and data loads, so it may suit a larger range of enduser types (media, data load, etc.) that can use common interface connectors.
High Speed LAN =2; Switched Legacy LAN=2

<u>Interface/Management</u>: Due to its huge market base, the network management tools for Switched LAN is superior today. This advantage will decrease.
High Speed LAN =2; Switched Legacy LAN=2

3.2.6. Redundancy: Redundant Switch or Redundant Cableplant

Two schemes to enhance network reliability will be traded; redundant switches and redundant cableplant. Redundant switching applies to active star schemes and involves multiple switches redundantly serving the network in either hot or cold standby mode. If a connection fails, there will be an additional switch to reroute the connection. If a cableplant connection is faulty, another standby cableplant will be activated to take over the route. One or a combination of these schemes could be used. This section trades redundant switches and redundant cableplant but in reality, both measures may be required for C4I applications.

<u>Cost/Acquisition</u>: Adding switches and cableplant will both add to acquisition cost. The cableplant redundancy would be the cheaper feature.
Switching =2; Cableplant=3

<u>Cost/Installation</u>: Redundant switching will be an additional component to install which will have its added connection costs. Adding cableplant covering different physical routes could be problematic.
Switching =2; Cableplant=2
<u>Cost/Maintenance</u>: More components is generally more maintenance. It is most difficult to maintain equipment that is distributed throughout the aircraft.
Switching =2; Cableplant=2

<u>Cost/Operation</u>: A controlling feature will have to be implemented which will route data to the main switch or the redundant switch in case of failure. The signaling protocol will handle the change in a transparent manner. The redundant switching

may be used to handle temporary bursts of traffic demand, if the interconnections are configured to handle increased traffic demand. Ganging of multiple switches will add a minimal amount of delay and should have little impact on the operation of the system. Like the redundant switches, there will have to be a control scheme which will route data through the redundant cableplant, if there is a failure. Many technologies already have such rerouting capability today.
Switching =2; Cableplant=2

Risk/Availability: Multiple switches and rerouting due to a malfunctioning switch or a broken connection are features that are generally available today.
Switching =2; Cableplant=2

Risk/Development: The basis of these features are generally already available. Customizing to C4I requirements should be fairly low risk.
Switching =2; Cableplant =2

Risk/Production: The features should add minimal complexity to the production process. Software is easy to replicate.
Switching =2; Cableplant =2

Interface/Performance: Potential performance improvements could result from the extra capacity added by the redundant switching portion of the network. The redundant portion of the network may be used to handle overload situations, enhancing the effective performance of the network. Redundant cableplant by itself will not add capacity.
Switching=3; Cableplant=2

Interface/Reliability: Both features inherently improve the reliability of the system.
Switching=3; Cableplant=3

Interface/Scalability: These features will be no more difficult to scale than the primary portion of the network, but it will add cost.
Switching=2; Cableplant=2

Interface/Reconfigurability: These features will be no more difficult to reconfigure than the primary portion of the network, but adds complexity.
Switching=2; Cableplant=2

Interface/Management: The management features will require customization for particular C4I application, but this should be fairly low risk. There will be little impact on active management by personnel. The management will be automated.
Switching=2; Cableplant=2

3.2.7. Switching Type: Software-based or Hardware-based

The switching technology is typically selected by the switch vendors. It is still a good idea for the advanced C4I network systems integrator to be familiar with the issues. It will help in the selection process for the switching vendor. The switching technology selection is based on unique traffic patterns, management needs, in-house expertise, size of staff, and budget. Latency, management and packet loss are very important performance parameters. Switches can be categorized as hardware or software based.

Hardware-based switches resemble bridges. They are fast, do the switching at the MAC layer, dynamically switch, and are nonblocking. The packets are received, buffered and transmitted without a CPU. The switches use either matrix (crossbar) or bus technology.

The matrix switch uses a matrix-search routine to find the intersection with a correct output address and routes input data accordingly. The disadvantages are that it can only monitor one input at a time and the number of inputs have to equal the number of outputs.

The bus-oriented switch is TDM, statistical or static, each port having its own time slot to send a packet. The time slots are fixed and known, which lead to consistent performance under varying load. The option handles both asynchronous and synchronous protocols. Inputs do not have to equal the number of outputs, resulting in a somewhat more convenient vehicle for protocol translation. It is possible to observe all traffic from a central point on the backplane. The technology is expensive and difficult to optimize to particular requirements.

Software-based switches resemble routers. They accept packets, synchronize the data, translate serial to parallel, examine the address, insert into fast memory, search the address table for the destination address, read the address from memory, translate parallel to serial, and finally transmit the packet out of the proper port. The advantage is greater manageability, but not in every case. The switch does not scale well and performance can drop with added stations and management features. The CPU and the shared memory are a potential single point of failure within the switch.

<u>Cost/Acquisition</u>: Hardware-oriented technologies are generally cheaper than software-based technologies. The matrix-based system will be the cheapest acquisition.
Matrix =3; Bus=2; SW=1

<u>Cost/Installation</u>: Installation cost of the three units will be the same.
Matrix =2; Bus=2; SW=2

<u>Cost/Maintenance</u>: It will be difficult to do maintenance related monitoring with the matrix-based switch as there is no central point to observe all the data flowing through

the switch. The bus has a central point. The SW-based switch is relatively complex with its CPU and fast memory. Complexity generally adds to maintenance cost.
Matrix =1; Bus=2; SW=1

Cost/Operation: Hardware-based systems are generally cheaper to operate than the more complex software-based system.
Matrix =2; Bus=2; SW=1

Risk/Availability: All three switching technologies are available today.
Matrix =2; Bus=2; SW=2

Risk/Development: The technologies are available. SW tends to be more flexible than HW so it should have lower developmental risk.
Matrix =2; Bus=2; SW=3

Risk/Production: C4I applications will require considerable customization that will be simpler to accomplish with SW-based switches.
Matrix =2; Bus=2; SW=3

Interface/Performance: The bus architecture probably has the best overall performance. The SW-based switch may have difficulty in handling added traffic.
Matrix =2; Bus=3; SW=1

Interface/Reliability: The matrix is the simplest technology. This is followed by the bus and the software-based switching technologies. The rating is based on simplest technologies being the most reliable.
Matrix =3; Bus=2; SW=1

Interface/Scalability: The SW-based switch does not scale well. The matrix switch probably scales the best as it is more operationally distributed than the bus with the common backplane. The time slots will be limited by high speed technology.
Matrix =3; Bus=2; SW=1

Interface/Reconfigurability: It should be the same for the technologies.
Matrix =2; Bus=2; SW=2

Interface/Management: Added management features on the SW-based system can negatively impact performance. The bus has a common point to observe all data, which may be valuable to management.
Matrix =2; Bus=3; SW=1

3.2.8. Cableplant: Fiber (MM, SM), Copper (Coax, STP, UTP), or Wireless (RF, IR)

Cost/Acquisition: Multimode and copper solutions are relatively inexpensive. Wireless solutions are the most expensive.
Multimode Fiber=3; Single Mode Fiber=1; Coax=2; Shielded Twisted Pair (STP)=3; Unshielded Twisted Pair (UTP)=3; RF=1; IR=1

Cost/Installation: RF and IR are essentially wireless systems, which require no cable installation. Single mode connectors are the most sensitive to the environment. This will be more of a factor with the subnetwork, which may have more cabling than the backbone.
Multimode Fiber=2; Single Mode Fiber=1; Coax=2; Shielded Twisted Pair (STP)=3; Unshielded Twisted Pair (UTP)=3; RF=3; IR=3

Cost/Maintenance: Wireless RF and IR systems are relatively complex, therefore presumably requiring high maintenance.
Multimode Fiber=2; Single Mode Fiber=1; Coax=2; Shielded Twisted Pair (STP)=3; Unshielded Twisted Pair (UTP)=3; RF=1; IR=1

Cost/Operation: No distinguishing factors are available.
Multimode Fiber=2; Single Mode Fiber=2; Coax=2; Shielded Twisted Pair (STP)=2; Unshielded Twisted Pair (UTP)=2; RF=2; IR=2

Risk/Availability: Commercial market share will determine availability.
Multimode Fiber=3; Single Mode Fiber=2; Coax=3; Shielded Twisted Pair (STP)=3; Unshielded Twisted Pair (UTP)=3; RF=1; IR=1

Risk/Development: Copper will have electromagnetic interference problems, with increasing data rates required by the increasing sophisticated applications and endusers. Glass will always be free of these interference problems. Wireless systems will probably have multipath and blocking problems. There are electromagnetic radiation-based health issues associated with the rf wireless option. Multimode fiber will be fairly rugged and free of interference.
Multimode Fiber=3; Single Mode Fiber=2; Coax=2; Shielded Twisted Pair (STP)=2; Unshielded Twisted Pair (UTP)=1; RF=1; IR=1

Risk/Production: Copper will require extensive electrical shielding to minimize electromagnetic interference, especially as the data rate increases. Fiber will require physically protective shielding. The fiber connections is a concern. At very high data rates, electrical connectors will also become a concern due to signal reflection.
Multimode Fiber=3; Single Mode Fiber=2; Coax=2; Shielded Twisted Pair (STP)=2; Unshielded Twisted Pair (UTP)=1; RF=1; IR=1

Interface/Performance: Fiber will provide virtually unlimited bandwidth with no electromagnetic interference problems. Copper provides limited bandwidth with

interference problems, increasing with data rate. Practical wireless solutions have very low rates and will have noise problems.
Multimode Fiber=3; Single Mode Fiber=3; Coax=2; Shielded Twisted Pair (STP)=1; Unshielded Twisted Pair (UTP)=1; RF=1; IR=1

Interface/Reliability: The wireless technologies will not be reliable because of multipath and blocking problems. The copper solution will also have less of an interference problem. Single mode cable is physically fragile.
Multimode Fiber=3; Single Mode Fiber=2; Coax=2; Shielded Twisted Pair (STP)=2; Unshielded Twisted Pair (UTP)=2; RF=1; IR=1

Interface/Scalability: Both fiber plants (mm and sm) have virtually unlimited capability over the distance typically required on C4I platforms. Coaxial cable's signal attenuation makes it relatively difficult to scale at higher rates over the longer distances required by AWACs aircraft. STP and UTP solutions are limited to 155Mbps. These options are potentially large electromagnetic radiators.
Multimode Fiber=3; Single Mode Fiber=3; Coax=2; Shielded Twisted Pair (STP)=1; Unshielded Twisted Pair (UTP)=1; RF=1; IR=1

Interface/Reconfigurability: This could be important for the subnetwork, which may need to be relatively reconfigurable depending on the C4I application. The backbone should require minimal reconfiguration capability. The wireless technologies are certainly the most reconfigurable options. The single mode option is not required and is relatively fragile. Copper is the most rugged, hence the most reconfigurable. Glass connectors are fragile.
Multimode Fiber=2; Single Mode Fiber=1; Coax=2; Shielded Twisted Pair (STP)=2; Unshielded Twisted Pair (UTP)=2; RF=3; IR=3

Interface/Management: No input.
Multimode Fiber=N/A; Single Mode Fiber=N/A; Coax=N/A; Shielded Twisted Pair (STP)=N/A; Unshielded Twisted Pair (UTP)=N/A; RF=N/A; IR=N/A

3.3. Technology Trade

3.3.1. Network Technology: ATM, Ethernet, Switched Ethernet, Fast Ethernet, Switched Fast Ethernet, Token Ring, or FDDI

ATM is rated against a variety of legacy LAN technologies. Most of the issues and discussions are based on those used for commercial terrestrial applications. The commercial issues must be emphasized in the downselection process for advanced C4I applications. This will ensure maximum COTS insertion and compatibility with commercial systems. A custom solution will be required only if the commercial requirements conflict with C4I mission requirements.

ATM is touted as the future of networking. It integrates the LAN and wide area network (WAN). It provides scaleable bandwidth on demand, with guaranteed levels of performance, using a connection-oriented protocol. This solution is a complete paradigm shift from today's pervasive connectionless networking technology. LAN emulation servers are required to reconcile connection to connectionless services. This adds overhead, complexity and cost. This is a relatively expensive solution to the enduser. The technology is not familiar to network managers and integrators. The final disadvantage is that applications do not exist to truly exploit ATM benefits, thus the network capabilities are presently underutilized by the enduser. Presently, the option is most suitable as a backbone technology. This network design is for an advanced C4I platform, so the primary disadvantages should be mostly eliminated through maturation. Applications will slowly be developed specifically for desktop to desktop ATM connectivity.

FDDI was designed for metropolitan area network (MAN) applications and has carved a stronghold in the network backbone market. The technology is stable, reliable, well understood, widely deployed (including on aircraft) and enjoys many advanced features. The NICs and hubs are still relatively complex and expensive compared to Legacy LAN systems. The enduser connections are unlikely to exploit the advanced features, thus the added expense probably does not make it viable for the enduser. This technology is not much cheaper than ATM and thus will not make significant inroads into the LAN market.

Ethernet is very pervasive and very limited in data rate capability. It provides 3-8 Mbps with a dedicated connection. The capacity is far less with shared users depending on the applications. Token Ring eliminates the contention problem but is still limited to relatively low throughput compared to FDDI or ATM.

<u>Cost/Acquisition</u>: Simple Ethernet network is the cheapest and available @ $100-200 (Intel) per NIC. Simple Fast Ethernet is priced at $260-300 (Intel) per NIC and is available. The next cheapest option is switched Ethernet, which adds ~$5,000 workgroup switch to the Ethernet NIC cost. Fast switched Ethernet is ~$280 per NIC and $1,300 for the switch adapter (Kalpana-Cisco Systems). FDDI is priced at ~$1,000 per NIC and is available. The cheapest available ATM system is the 25 Mbps ATM at $550 per NIC and $5,300 for a 1 Gbps switch (First Virtual Inc.) . ATM @ 155 Mbps is $1,500 per NIC adapter pair and ~$30K for a 16 port switch (Fore Systems). Cost for ATM systems will decrease rapidly with time.
ATM =2; Ethernet=3; Fast Ethernet=2; Token Ring=2; FDDI=2; Switched Ethernet=3; Fast Switched Ethernet=3

<u>Cost/Installation</u>: Same as arguments given in logical topology section for bus, ring, active star, passive star. All the network technologies can be used with fiber or copper (with ≤ 155Mbps), so ease of installation is the same. The Ethernet option has a large experience base, so it will be given an advantage.

ATM =2; Ethernet=3; Fast Ethernet=2; Token Ring=2; FDDI=2; Switched Ethernet=3; Fast Switched Ethernet=2

Cost/Maintenance: Should be similar at the component level. Maintenance will involve replacing electronic cards or modules, which are similar whether they are ATM or Ethernet. The cableplant maintenance is the same for rates up to 155 Mbps where both glass and copper can be used. At higher rates, fiber would be required, making maintenance more difficult. The Ethernet experience base is a cost advantage that will decrease with time as ATM technology matures.
ATM =2; Ethernet=3; Fast Ethernet=2; Token Ring=2; FDDI=2; Switched Ethernet=3; Fast Switched Ethernet=2

Cost/Operation: No inputs.

Risk/Availability: All of the options are available, but some of the more advanced technologies are relatively immature. In order of decreasing maturity: Ethernet, Token Ring, Switched Ethernet, Fast Ethernet, FDDI, Fast Switched Ethernet, ATM. ATM's disadvantage will decrease with time.
ATM =2; Ethernet=3; Fast Ethernet=2; Token Ring=2; FDDI=2; Switched Ethernet=3; Fast Switched Ethernet=2

Risk/Development: The rating would be the same as risk/availability, as the knowledge base will probably be proportional to availability. ATM is presently relatively immature, but is growing fast. It still must be rated a higher risk than the other legacy technologies. Ethernet will have the most rugged components and thus should be the easiest to customize and certify for C4I applications.
ATM =2; Ethernet=3; Fast Ethernet=3; Token Ring=2; FDDI=2; Switched Ethernet=3; Fast Switched Ethernet=2

Risk/Production: The order of complexity will determine the production risks.
ATM =2; Ethernet=3; Fast Ethernet=2; Token Ring=2; FDDI=2; Switched Ethernet=3; Fast Switched Ethernet=2

Interface/ Performance: ATM will ultimately provide the best performance as it is a connection-oriented system with a large selection of available data rates. FDDI would follow with 100 Mbps throughput and a relatively sophisticated network access scheme (relative to Ethernet). Fast switched Ethernet can be configured with dedicated contention free connections with an effective 30 Mbps throughput to the enduser. Ethernet is last with 8 Mbps maximum throughput to a dedicated enduser. Throughput is far less with a shared network depending on the applications. The Ethernet schemes and Token Ring are not suitable for backbone applications. Their throughput is too low to handle the rates required for a diverse range of C4I platforms, handling mixed media and functions.

ATM =3; Ethernet=1; Fast Ethernet=1; Token Ring=1; FDDI=2; Switched Ethernet=1; Fast Switched Ethernet=1

Interface/Reliability: The rating would be the same as risk/availability, as the reliability will be proportional to maturity, simplicity, and ruggedness. Higher rates require relatively sensitive cable connectors.
ATM =2; Ethernet=3; Fast Ethernet=2; Token Ring=2; FDDI=2; Switched Ethernet=3; Fast Switched Ethernet=2

Interface/Scalability: ATM has the largest range of data rates available. The second option is the switched legacy LAN systems, followed by the contention constrained legacy LANs.
ATM =3; Ethernet=1; Fast Ethernet=1; Token Ring=1; FDDI=2; Switched Ethernet=1; Fast Switched Ethernet=1

Interface/Reconfigurability: This follows the same logic for bus, ring, passive star or active star arguments. ATM can handle a larger variety of different rates by replacing modules in the PC and the switch, allowing it to handle a variety of traffic loads. Ethernet, Token Ring and FDDI are shared medium, so attachments can be made along a single shared cable (i.e., not connection-oriented like ATM). This is more suitable for reconfigurability and will have the feel and look of the daisy chain system presently used in aircraft to distribute entertainment and control data.
ATM =2; Ethernet=2; Fast Ethernet=2; Token Ring=2; FDDI=2; Switched Ethernet=2; Fast Switched Ethernet=2

Interface/Management: The maturity levels of the options will determine which technology has the largest management database.
ATM =1;Ethernet=3; Fast Ethernet=2; Token Ring=2; FDDI=2; Switched Ethernet=3; Fast Switched Ethernet=2

3.3.2. Transport Protocol: 25 Mbps ATM, DS-3 (45 Mbps), SONET (OC-3, OC-12, OC-24, OC-48)

Cost/acquisition: The cost tracks fairly well with data rate with an abrupt increase at 622 Mbps due to the requirement for single mode fiber and lasers.
25 Mbps ATM=3; 45 Mbps DS-3=3; OC-3=3; OC-12=1; OC-24=1; OC-48=1

Cost/Installation: Both relatively cheaper and relatively rugged multimode fiber or copper options can be used for data rates up to 155 Mbps. Higher rates require expensive and more sensitive single mode laser and fiber technology.
25 Mbps ATM=3; 45 Mbps DS-3=3; OC-3=3; OC-12=1; OC-24=1; OC-48=1

Cost/Maintenance: The maintenance cost should be the same for rates up to 155 Mbps. At higher rates lasers and single mode fiber would be required, adding maintenance cost.
25 Mbps ATM=3; 45 Mbps DS-3=3; OC-3=3; OC-12=1; OC-24=1; OC-48=1

Cost/Operation: Operation cost should be transparent to the actual data rate. The system is automated.
25 Mbps ATM=2; 45 Mbps DS-3=2; OC-3=2; OC-12=2; OC-24=2; OC-48=2

Risk/Availability: All of the above mentioned technologies are readily available through OC-48 today, except for OC-12 which is not a popular standard.
25 Mbps ATM=3; 45 Mbps DS-3=3; OC-3=3; OC-12=1; OC-24=3; OC-48=3

Risk/Development: The least risk will be experienced by developing and certifying copper or multimode LED technologies for C4I applications. There is considerable experience certifying similar technologies for aircraft applications.
25 Mbps ATM=3; 45 Mbps DS-3=3; OC-3=3; OC-12=1; OC-24=1; OC-48=1

Risk/Production: The copper or multimode fiber, with its LED based transport components will have the lowest production risks. There is considerable experience producing similar technologies for aircraft applications.
25 Mbps ATM=3; 45 Mbps DS-3=3; OC-3=3; OC-12=1; OC-24=1; OC-48=1

Interface/ Performance: The highest rate options will deliver the most performance once the applications are optimized for the higher rates and the traffic load is excessive for the lower rate options. These performance parameters are also very dependent on the switching equipment and enduser equipment.
25 Mbps ATM=1; 45 Mbps DS-3=1; OC-3=2; OC-12=3; OC-24=3; OC-48=3

Interface/Reliability: The transport protocols using copper or multimode LED based technologies will be more reliable than lasers or single mode fiber. The lasers require TE coolers and the single mode connectors have questionable reliability in the harsh environments required for C4I applications.
25 Mbps ATM=3; 45 Mbps DS-3=3; OC-3=3; OC-12=1; OC-24=1; OC-48=1

Interface/ Scalability: Not applicable to transport protocols.

Interface/Reconfigurability: Similar to previous reasoning, the rates up to 155 Mbps will be more configurable from a physical viewpoint, as their connectors will be more rugged than the higher rate single mode connectors. The technologies will also be eyesafe.
25 Mbps ATM=3; 45 Mbps DS-3=3; OC-3=3; OC-12=1; OC-24=1; OC-48=1

Interface/Management: Not applicable to transport protocols.

4.0. ARCHITECTURE AND TECHNOLOGY DOWNSELECT

4.1 Architecture Downselect

Conclusions are taken from the last column of the trade templates. A summary of each conclusion is presented.

4.1.1. System: Integrated or Federated

Backbone: The networks will be integrated wherever possible to reduce acquisition, installation, maintenance, and operation cost. The risks are manageable under the time frame of this network; delivery by approximately the year 2005. A study will have to be completed to determine which functions can be integrated onto common network solutions. The performance will be superior because of more efficient sharing and utilization of resources. Reconfigurability will be improved by using common interfaces for a variety of functions. Management resources will be shared reducing cost.

Subnetwork: This portion of the network will also be integrated wherever possible to increase the commonality of interfaces to the endusers. This reduces cost by reducing the parts count and improves configurability by allowing different enduser functions to connect to any interface on the network. The server will then be sufficiently smart to recognize the enduser type and function. The risks are manageable under the time frame of this network.

4.1.2. Data Format: Analog or Digital

Backbone: The system will be completely digital because of noise immunity, enhanced data processing capability, and parts count reduction. It is also the trend in the commercial sector. COTS will be a major factor in reducing cost and improving interoperability with commercial systems.

Subnetwork: Same advantages as stated for the backbone.
There will be no unique connectors which would reduce commonality between endusers. Analog solutions tend to use unique connectors for video and audio.

4.1.3. Physical Topology

Backbone: The system will be distributed. The reliability of the switches will be sufficiently high to allow their placement in underutilized locations throughout the aircraft. This will improve survivability, free valuable space in overutilized electronic bays, and be compatible with the commercial trend for distributing resources.

Subnetwork: Same as the backbone.

4.1.4. Logical Topology

Backbone: The trade concluded that the active star, bus and ring were overall equally strong candidates. However, the active star is the only solution that can provide the rate required by advanced C4I platforms. This is why the performance trade parameter was heavily weighted. The selected design will be a cross strapped web of components similar to the active star topology. This is required to provide a dual homing capability to eliminate a single point of failure. Each component on the subnetwork must have at least two potential connections to the network below it. The subnetwork LAN switch will have at least two connections to two ATM switches on the backbone. The endusers will have two connections to two LAN switches or directly to two ATM switches, if it is using a legacy LAN NIC or an ATM adapter card, respectively. Advanced C4I requirements will require higher bandwidths per enduser with time, which will strain the capability of any connectionless system (bus, tree and ring). The star topology is selected for connecting switches, because it lends itself to connection oriented networks. Connection-oriented networks will be optimum for bandwidth hungry systems and future scalability. The Star topology will handle the largest number of nodes and the highest bandwidth per node.

Subnetwork: The subnetwork will be a star for similar reasons as stated for the backbone of the network. It will add complexity to the overall system, but enhance it's scalability and reliability. These features will be more important for advanced C4I applications that will take advantage of future sophisticated enduser equipment. It will allow for both connection-oriented and switched connectionless protocols on the same physical network.

4.1.5. Network Type

Backbone: High Speed LAN and Switched Legacy LAN had similar scores. The backbone will be a high speed LAN technology because the advanced C4I platform will require maximum flexibility in handling a wide range of rates that a switched LAN cannot provide. A higher premium will be placed on flexibility than initial cost. It is assumed that applications will soon be optimized for connection-oriented protocols.

Subnetwork: The subnetwork will be capable of delivering both High Speed LAN and switched Legacy LAN to the enduser. The cableplant will be compatible so that the two technologies are easily interchangeable by switching modules. The legacy system will be used to reduce cost and to take advantage of existing applications optimized for the connectionless protocol. The subnetwork must be able to use the high speed LAN technology, because advanced C4I platforms will require maximum flexibility in handling a wide range of rates that a switched LAN cannot provide.

4.1.6. Redundancy

Backbone: Multiple switches and connectors will be used to enhance the reliability of the system. A single faulty switch is not allowed to disable a portion of the network. A single point of failure is not tolerated on C4I networks. There must be a modular process for providing redundant switching and connections to eliminate any single point of failure.

Subnetwork: Single point of failure is not tolerated with C4I functions. There must be a modular process for providing redundant Legacy LAN NICs and ATM adapter cards onto the enduser station. The protocols have to be customized to handle this redundancy, preferably at a sufficiently low level so that the application layer is never interrupted.

4.1.7. Switching Type

Presently, the switching vendor will determine this solution.

4.1.8. Cableplant

Backbone: The backbone will use fiber because it will transport high data rates and will remain relatively undisturbed. Relatively few connect/disconnects will occur. The cableplant will be multimode fiber, which has already been inserted into aircraft. The solution can deliver the data rate requirements for the distance required by the backbone, without any electromagnetic radiation issues. If required, high data rate single mode laser transmitter technologies can be used with this cableplant.

Subnetwork: Similar conclusions as stated for the backbone. However, since the rate is much lower, the path much shorter, and relatively frequent connect/disconnects, STP can also be used as the cabling plant. Radiation will be less of a problem at the lower rates and shielding of short length will not add significant weight, cost, or space penalties. The connectors will be better suited for the frequent physical handling it will experience over the life cycle of the plane. Multimode will be used if higher data rates are required for delivery to the enduser and radiation and interference is a concern.

4.2. Technology Downselect

4.2.1. Network Technology

Backbone: It is very apparent that the Legacy LAN and switched Legacy LAN protocols have a limited throughput and unsophisticated network access schemes. FDDI has the maximum throughput of 100 Mbps. Ethernet has a maximum throughput of ~ 8 Mbps, depending on how it is used. An important advantage of ATM technology is its scalability and flexibility, presently delivering capacity ranging from 25 Mbps to 2.4 Gbps. The low rate is the 25 Mbps ATM adapter card, with the cost being only four times that of the Ethernet card and decreasing. A variety of rates are provided (45 Mbps, 155 Mbps, 622 Mbps, 1.2 Gbps). The goal is to design a network that will satisfy a large fleet of varying C4I platforms that will have varying data handling requirements. A small UAV or fighter with simple sensors may only require 25 Mbps backbone capacity. The Advanced AWACS, with numerous high definition SAR inputs, may require in the Gbps range and more. ATM is the only protocol with the flexibility to deliver a wide range of rates over the same cableplant and switching chassis. If a higher rate is required, only the adapter card at an enduser and a module in the switch need to be replaced.

Another important advantage of the protocol is the ability to deliver mixed media. These features reduce the number of networks required on the aircraft by enabling the integration of functions with different media over fewer shared network resources. Savings are achieved through reduced acquisition, installation, maintenance and operating costs on the networks. Also, there will be weight and power savings by sharing onboard resources.

Subnetwork: Switched legacy LAN and ATM technologies will be used in the subnetwork. They can utilize the same cableplant. The future for the subnetwork (i.e, all the way to the desktop) is only arguably towards pervasive ATM. This conclusion is consistent with the product line of commercial ATM vendors, who realize they have to deliver legacy LAN to market their product, because of its entrenched market base.

4.2.2. Transport Protocol

Backbone: The SONET technology is chosen as the solution. It provides the largest range of choices that are relatively interchangeable, depending on the application. They all use the same cableplant. Depending on the C4I requirement, the backbone could first be equipped with OC-3 and then be upgraded by replacing modules on the switches. The backbone will be limited to 155 Mbps SONET. This allows the flexibility to choose copper or multimode fiber with LED technology. The cross-strapped nature of the architecture makes the effective rate between switches on the backbone much higher. Higher rates require single mode fiber and lasers. This is disadvantageous from the viewpoint of cost and ruggedness. Lasers require TE

cooling. Also, multiple pin multimode connectors are widely available today for aircraft applications and will remain significantly cheaper and more rugged then single mode fiber multipin connectors.

Subnetwork: 25 Mbps to 155 Mbps, in addition to Switched Ethernet, will be used by the subnetwork. This will easily satisfy the data capacity required for the foreseeable future for workstations. Electromagnetic shielding of short lengths of copper should not be a problem at the lower rates.

5.0. ATM-Based ISSN NETWORK DESIGN

Architecture Design: Based on the trade study completed during Task 2 of the ISSN contract, we propose a top-level architecture (Fig. 5.0.1), which has a primary backbone that is a distributed, cross-strapped, active star. This is consistent with the selection of ATM/SONET for the backbone network. We propose a combination of ATM and switched Ethernet for the subnetwork to provide the final connectivity to the enduser. This ability to use two protocols over the same cableplant demonstrates the flexibility of the architecture. An ATM to Legacy LAN switch is required to provide the interface between switched Ethernet and ATM. The ATM portion will be limited to 155 Mbps to avoid the use of single mode laser-based transmitter technologies. This also allows the possibility of copper-based cableplants.

Network Redundancy: If required, the switches, cableplant (connection), and the endusers adapter cards will be redundant as shown in Figure 5.0.1. There will be no single point of failure across the backbone and subnetwork. Each backbone switch is connected to at least two other switches. The subnetwork redundancy is achieved by using two NIC cards on each station, which will be connected to two cross-strapped switches that are part of the backbone. The control over the adapter cards may be accomplished by writing a quasi-session controller between the transport layer, which probably resides on the adapter card, and the application layer, residing on the PC or workstation. If the connection to one of the NICs is broken, the connection will be rerouted through the spare NIC.

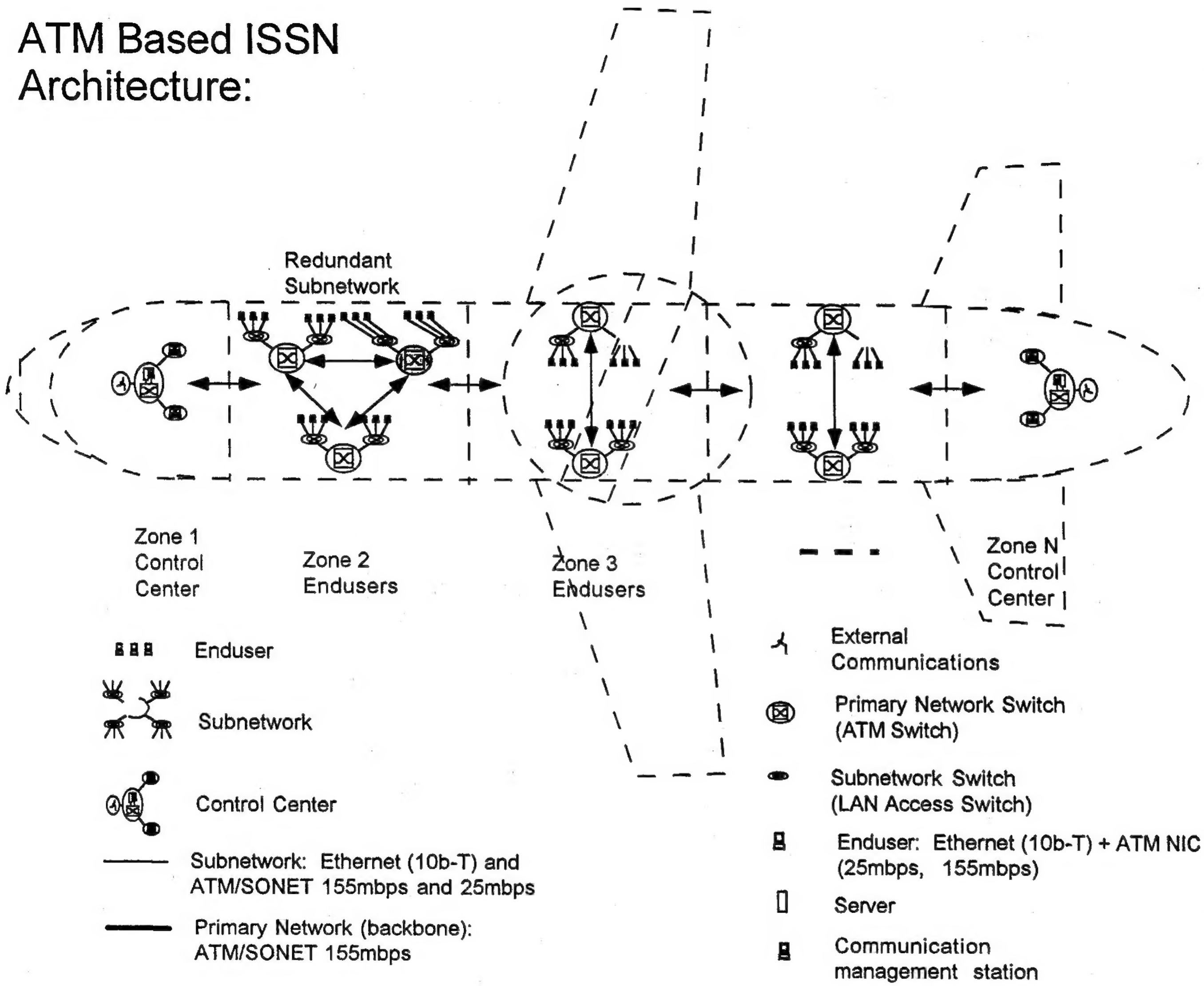


Figure 5.0.1 Top-Level Design of ATM-Based Integrated Services Switched Network

6.0. CONCLUSION

The new ATM-based architecture is a system that will eventually operate seamlessly across WAN and LAN networks. This capability will probably occur within the life cycle of a new C4I platform. A large effort would be required to make the custom phase I architecture have the same capability. The effort would essentially replicate the effort of the ATM Standards Forum. In addition, ATM is intrinsically a shared resource protocol and thus will use its capacity more efficiently than the multiplexing scheme used with the phase I architecture. This feature can also be used to efficiently design redundancy features into the network.

Finally, the ATM architecture is a standardized signaling and routing protocol, while a custom solution would be required to develop the same capability for the Task 1 architecture. It is not evident yet whether ATM will provide the same video, audio and data quality. High quality will probably be delivered with further development at the application level. The high data quality observed during the task 1 system demonstration was due to the dedicated connection process, eliminating buffering of data. ATM is a compromise between optimum performance for data, voice and video transmission, so the quality to the enduser must be closely monitored.

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